Project Modification Report/Environmental Assessment

Technical Appendices

Sagamore Marsh Restoration Study
Bourne and Sandwich, Massachusetts

November 1996

US Army Corps
of Engineers
New England Division

EOEA File # 10174

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APPENDIX A

TOPOGRAPHIC SURVEY

A topographic survey of the Sagamore Marsh and adjacent areas was performed early in the study. The purpose of the survey to determine the lay of the land within and surrounding the marsh. All survey work was coordinated with the Bourne and Sandwich Conservation Commissions. Elevations were surveyed in the following locations:

* in the vicinity of the existing outlet at the Cape Cod Canal;
* within the marsh; and
* at houses and yards on the south-west side of Phillips Road.

The purpose of the topographic survey in the vicinity of the existing outlet was to determine the quantities of excavation required to remove the existing culverts and replace them with larger culverts, and the quantity of excavation required to widen the channel. A detailed topographic survey was performed from the culvert at the Canal north 1,300 feet into the marsh, 150 feet on either side of the riprapped channel.

The purpose of the survey within the marsh was to determine the size and elevations of the existing channels, and the elevations of the marsh surface. This information was used in the Hydraulic Model and Analysis and in the Environmental Model and Analysis.

Channel and marsh surface elevations were recorded every 100 feet from 1,300 feet into the marsh to 2,800 feet into the marsh, as measured along the channel from the culvert at the Canal. The surveys extended 25 feet on either side of the channel.

In addition, cross-sections of the marsh were surveyed at representative locations, extending from elevation +10-feet NGVD on the west side of the marsh to elevation +10-feet NGVD on the east side (the marsh surface elevation ranges from approximately 2.5-3.5 feet NGVD). Due to the difficulty and associated cost of performing a topographic survey within the marsh, the number of cross-sections which could be surveyed was limited to six. The cross-sections are referred to as "transects" in figures and in subsequent text, and are numbered for ease of reference. Transect 3 was located in an area in which dredged material was placed in the mid-1930's. That cross-section was surveyed in order to determine the elevation of fill in that area in relation to the unfilled portion of the marsh. Cross-section number 3 was not used in the hydraulic analysis.

In some cases it was necessary to cut lines of sight through the tall phragmites in the marsh and other vegetation surrounding the marsh in order to perform the survey. The cutting of vegetation was kept to the minimum required for lines of sight, and most vegetation has now grown back.

The houses on the south-west side of Phillips Road, along with the grassed area on the marsh side of the houses, were surveyed to determine the level of flooding in the marsh that would affect them. The house and yard elevations are shown in **Table A-1**. It was determined that houses and yards on Pilgrim Road, Marsh Pond Road, Vineyard Circle, and Sachem Drive were all higher in elevation than all proposed tide levels within the marsh.

Table A-1
Elevations of Houses and Yards on Phillips Road Adjacent to Sagamore Marsh

House Number	Elevation of First Floor (ft NGVD)	Elevation of Low Point At House (ft NGVD)	Elevation of Low Point Behind House (ft NGVD)	Distance from Phillips Rd. to Rear of Parcel (ft)	Approximate Distance from Phillips Rd. to Low Point Behind House (ft)
80	10.51	6.92	5.06	100	140
150	16.15	7.65	5.42	378	120
DIRT ROAD EXTENSION OF PILGRIM ROAD					
154	14.70	6.73	5.68	120	130
162	13.47	7.32	8.19	120	115
170	14.95	6.52	6.44	120	110
178	16.43	6.91	5.28	120	160
186	15.26	6.70	4.78	120	140
200	14.06	5.60	6.34	120	115
204	13.66	6.30	5.30	120	140
206	10.25	6.39	7.34	120	110
206A	9.34	6.10	5.65	120	120
208	9.48	5.45	5.91	120	120
210/210A	13.82	5.67	5.91	120	120
212	13.76	7.00	7.06	120	95
220	14.60	10.30	5.21	120	110
228	14.47	7.47	3.75	120	175
230	13.96	6.46	5.86	120	140
234	11.05	8.12	6.72	120	110
236	10.74	8.50	5.12	120	140
240	16.20	8.47	5.13	120	130
244	13.16	6.19	3.17	120	150
248	11.05	7.39	5.10	120	125
250	14.77	8.37	6.39	120	120
252	13.28	5.60	4.47	120	130
254	16.51	8.55	6.23	120	100
258	9.48	7.03	4.75	120	145
260	10.29	6.02	4.82	120	140
262	10.08	6.25	5.03	120	140
APPROXIMATE NORTH-WESTERLY LIMIT OF FILL IN MARSH					

Table A-1
Elevations of Houses and Yards on Phillips Road Adjacent to Sagamore Marsh
(Continued)

House Number	Elevation of First Floor (ft NGVD)	Elevation of Low Point At House (ft NGVD)	Elevation of Low Point Behind House (ft NGVD)	Distance from Phillips Rd. to Rear of Parcel (ft)	Approximate Distance from Phillips Rd. to Low Point Behind House (ft)
264	10.65	7.48	5.14	120	135
266	8.42	6.15	5.15	120	120
268	10.40	8.77	5.24	120	130
270	9.38	7.71	4.94	120	160
272	11.36	5.87	5.05	120	100
274	14.02	5.60	5.08	120	140
278	16.34	7.91	5.27	120	165
282	15.49	6.85	6.08	120	150
284	15.61	8.06	10.90	120	130
290	12.06	8.29	4.89	120	210
292	14.03	11.41	4.75	120	215
294	10.30	9.44	4.75	120	215
296	16.25	7.12	4.31	120	270
298	12.45	8.47	4.34	120	240
300-302	13.57	9.27	5.23	120	110
304	11.16	10.77	4.75	120	150
306	12.22	9.16	5.07	120	115
308	14.45	6.46	4.77	120	125
310	16.31	10.03	7.24	120	120
312	16.60	8.32	7.50	118	100
314	14.56	6.74	4.63	116	130
318-320	13.91	6.28	4.69	95	70
328	17.28	10.26	5.88	90	200
332	9.30	8.29	7.95	112	125
334	11.87	7.47	6.37	122	125
338	14.69	12.01	6.99	143	140
340	15.09	13.49	7.16	154	140
342	19.12	10.48	8.23	164	175
346	16.64	10.29	7.81	185	130
348	16.07	9.60	7.16	100	145
350	12.32	9.26	9.02	100	100
350X	13.35	9.95	9.32	N/A	175
352X	14.18	10.35	10.06	N/A	250
352	12.75	9.28	8.81	104	80
@ 356:					
Cottage 1	12.66	11.46	11.96	N/A	N/A
Cottage 2	11.98	10.26	11.96	N/A	N/A
Cottage 3	11.59	10.46	9.97	N/A	N/A
Cottage 4	9.96	8.35	8.39	N/A	N/A
Cottage 5	11.26	9.56	10.44	N/A	N/A
Cottage 6	10.38	9.29	10.44	N/A	N/A
Cottage 7	11.33	10.10	11.96	N/A	N/A
Cottage 8	9.79	8.13	8.39	N/A	N/A
Cottage 9	9.64	7.90	8.39	N/A	N/A
Cottage 10	9.24	8.11	8.39	N/A	N/A
Shed	9.36	8.30	8.39	N/A	N/A

APPENDIX B

HYDRAULIC AND HYDROLOGIC ANALYSIS

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HYDROLOGY AND HYDRAULICS APPENDIX
SAGAMORE SALT MARSH RESTORATION
SAGAMORE, MASSACHUSETTS

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HYDROLOGY AND HYDRAULICS APPENDIX
SAGAMORE SALT MARSH RESTORATION
SAGAMORE, MASSACHUSETTS

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HYDROLOGY AND HYDRAULICS APPENDIX
SAGAMORE SALT MARSH RESTORATION
SAGAMORE, MASSACHUSETTS

1. EXECUTIVE SUMMARY

Construction of the Cape Cod Canal in the 1930s, in conjunction with accretion of littoral material, caused significant degradation of the Sagamore Salt Marsh, located north of the canal. The purpose of this study was to determine optimum culvert and channel configurations to restore as much of the marsh as possible without adversely affecting homes, yards, septic systems, or wells in its surrounding area. This appendix dealt specifically with surface water flooding. Analysis of the potential impact on septic systems and freshwater wells is in the Groundwater Appendix.

Based on the analysis completed, one 6- by 12-foot culvert under the Canal Service Road and Scusset Beach Road will be sufficient to flood enough of the salt marsh to restore approximately 50 acres.

2. AUTHORITY

Authority to perform this investigation is provided under Section 1135 of the Water Resources Development Act of 1986 (PL 99-662), as amended. Section 1135 entitled "Project modification for Improvement of Environment" states, in part:

> " The Secretary is authorized to review the operation of water resources projects constructed by the Secretary before the date of enactment of this Act to determine the need for modification in the structures and operations of such projects for the purpose of improving the quality of the environment in the public interest."

This study involves restoration of a marsh which was significantly degraded by construction of the Corps Cape Cod Canal, and, therefore, is appropriate under Section 1135 authority.

3. BACKGROUND

The Sagamore Marsh is located in a coastal watershed, approximately 1.8 square miles in drainage area, between the towns of Sandwich and Bourne, Barnstable County, in eastern Massachusetts. The marsh lies on the north side of the Cape Cod

Canal, at the east end. A freshwater stream, originating near Williston Road, feeds the marsh. The stream begins at a pond, which appears to be spring-fed, and flows in a southerly direction through the marsh, discharging into the Cape Cod Canal. The stream has a total length of about 2.2 miles, and a total drop in elevation of approximately 6 feet. A delineation of the watershed and wetland is shown on plate B-1.

Before construction of the canal, the marsh was drained by Scusset River, which flowed from the marsh into Cape Cod Bay. Dredged material from construction of the canal was placed in the marsh in the mid-1930s. To allow for runoff drainage, a southerly flowing channel was constructed connecting to the Cape Cod Canal. Circular culverts, 48 inches in diameter, were installed under the Scusset Beach Road and Canal Service Road. Construction of the canal, the changed direction of the wetland drainage, and the subsequent restraint of tidal inflows by culvert construction altered physical conditions of the marsh, changing it from saltwater to freshwater marsh. Location of the reinforced concrete pipe (RCP) culverts is shown on plate B-2.

Three potable water supply wells are located near the Sagamore marsh (see plate B-2). Two are located near the headwaters of the stream, and the third at the southeastern part of the marsh next to the utility road. One of the two wells in the northern end, Beach well, is presently active, serving as an auxiliary source for increased water demands in the summer. This well, operating since 1958, was reported to have an average pumping rate of 0.05 MGD for the year 1994 (page 54, Appendix E). The second well, near the headwaters of the marsh, has been abandoned, and there are no immediate plans to use it. The third well, located near the utility road, is used by the Massachusetts Department of Environmental Management to supply water to Sagamore Beach bath house. Detailed information on potable wells and groundwater analysis is provided in Appendix E of this report.

The purpose of this study was to determine optimum culvert and channel configurations to restore as much of the marsh as possible, without adversely affecting homes, yards, septic systems, or wells. This was accomplished by estimating the frequency of flooding necessary to restore salt marsh, determining the effects of freshwater input, estimating an interior flood level which would not impact homes or yards, and determining the optimum culvert size to meet the objectives.

4. SITE HYDROLOGY

a. Tidal Regime. In the study area, tides are semi-diurnal, with two high and low waters occurring during each lunar day (approximately 24 hours and 50 minutes). The resulting astronomic tide range varies constantly in response to relative positions of the earth, moon, and sun, with the moon having the primary tide producing effect. Maximum tide ranges occur when orbital cycles of these bodies are in phase. A complete sequence of astronomic tide ranges is approximately repeated over an interval of 19 years, known as a tidal epoch. Coastal storms and hurricanes can cause tides to be much higher than astronomically predicted.

Although long term tidal measurements are not available at the site, an approximation can be developed from short term tidal measurements previously conducted by the NOS in the Cape Cod Canal at Sagamore, with correlation to historical tide data at the Boston, Massachusetts, National Ocean Survey (NOS) gage, located 30 miles north of the site. Also, tidal flood profiles, developed by the Corps for the open ocean along the New England coastline were used to estimate tidal flood frequencies at Cape Cod Canal, Sagamore (see plates B-3 and B-4). A summary of estimated tidal datums at the subject site is shown in table B-1.

Based on the tidal regime at Sagamore, the Corps estimated that eight flooding times per month are required to restore salt marsh. This frequency corresponds to an estimated high tide of 4.95 feet NGVD, slightly higher than the mean spring high water.

b. Freshwater Drainage Area. Based on 1:25,000 U.S. Geological Survey (USGS) quadrangle sheets (photo revised 1979), and recent survey information, the total drainage area was approximated as 1.8 square miles. Of this area, the Sagamore Marsh occupies 0.4-square mile, with minimum elevations ranging between 2 and 4 feet NGVD. Two small connected ponds, approximately 0.5 acre in surface area each, are located to the northeast of the marsh. These two ponds receive runoff from an area of approximately 28 acres and appear to be spring-fed. Since the ponds are located at the headwaters of the stream feeding the Sagamore marsh, and because of the difference in elevation from the ponds' outlet to the main stem, the freshwater condition of the ponds is infrequently impacted by saltwater interchange within the marsh.

5. CLIMATOLOGY

a. General. The Sagamore Marsh area and Cape Cod have a temperate climate. Due to direct coastal exposure, periods of intense precipitation, produced by local thunderstorms and large weather systems of tropical or extratropical origin, are frequently experienced. In the winter, coastal storms frequently bring rainfall instead of snow due to the moderating influence of the Atlantic Ocean. In the summer, cooling is provided by easterly and southerly sea breezes, thunderstorms from the west, and cool air from the north. Prevailing winds are northwesterly in winter and southwesterly in summer.

TABLE B-1

ESTIMATED TIDAL LEVELS AT SAGAMORE

(Estimated from short term NOS measurements conducted within the Cape Cod Canal at Sagamore, with correlation to the Boston, Massachusetts NOS Tide Gage Data and Corps of Engineers Tidal Flood Profiles, New England Coastline, dated September 1988)

	Tide Level (ft, NGVD)
100-year Frequency Flood Event	10.4
50-year Frequency Flood Event	9.9
10-year Frequency Flood Event	8.3
Maximum Predicted Astronomical High Water	6.5
Mean High Water Spring (MHWS)	4.6
Mean High Water (MHW)	4.1
Mean Tide Level (MTL)	0.1
National Geodetic Vertical Datum (NGVD)	0.0
Mean Low Water (MLW)	-3.8
Mean Lower Low Water (MLLW)	-4.1
Mean Low Water Spring (MLWS)	-4.4
Minimum Predicted Astronomical Low Water	-5.9

b. Temperature and Precipitation. Climatological records, approximately 18 miles northwest of Sagamore, at the Plymouth, MA, U.S. Weather Bureau gage, dating back to 1948, are available. These records are considered representative of the area. Average annual temperature based on these gage readings is 48.8 degrees Fahrenheit. Average annual precipitation at Plymouth is 47.53 inches. Average precipitation, temperature and snowfall values recorded at Plymouth, MA are listed in table B-2. Peak storm rainfall frequency-duration data, as reported in U.S. Weather Bureau Technical Paper No. 40 (TP-40), are summarized in table B-3.

TABLE B-2

MONTHLY CLIMATOLOGIC DATA
PLYMOUTH, MA
(Period of Record - 1948 -1993)

Month	Precipitation Average Mean (in)	Temperature (°f) Maximum	Temperature (°f) Average	Temperature (°f) Minimum	Snowfall Mean (in)
January	4.07	47.0	27.5	4.0	10.35
February	3.93	46.0	27.7	8.0	9.65
March	4.24	53.0	36.1	19.0	5.79
April	4.26	62.0	45.0	30.0	0.76
May	3.58	74.0	55.4	39.0	0.00
June	3.03	83.0	65.0	50.0	0.00
July	3.08	88.0	71.0	57.0	0.00
August	4.29	85.0	69.5	55.0	0.00
September	3.90	78.0	61.9	45.0	0.00
October	3.83	70.0	52.0	35.0	0.06
November	4.85	58.0	42.5	27.0	0.78
December	4.47	50.0	31.8	7.0	5.26
Annual	47.53	88.0	48.8	4.0	32.65

TABLE B-3

RAINFALL - FREQUENCY - DURATION
USWB TECHNICAL PAPER 40
(Rainfall in Inches)

Annual Frequency Percent	Annual Frequency Year	Duration in Hours 1	2	6	12	24
50	2	1.2	1.6	2.3	2.7	3.3
20	5	1.6	2.0	2.7	3.4	4.0
10	10	2.0	2.4	3.3	4.0	4.6
2	50	2.5	3.0	4.1	5.1	6.0
1	100	2.9	3.4	4.7	6.0	7.0

c. Runoff. As shown in table B-2, precipitation is fairly uniform throughout the year; therefore, statistical analysis of annual precipitation can be used. Average annual runoff in the study area from U.S. Weather Bureau Hydrologic Atlas HA 7 is about 24 inches (2 csm based on the drainage area). This amounts to about 50 percent of the average annual precipitation, or an average annual flow rate of 3.6 cfs. Table B-2 shows that coastal weather keeps a small snowpack resulting in little snow melt in the spring. For this reason, the principal runoff producing events are rainstorms.

6. HYDROLOGIC ANALYSIS

The HEC-IFH Interior Flood Hydrology Package, April 1992 computer program was selected to analyze the Sagamore Marsh site. Rainfall event information for various return periods was developed using USWB TP-40 as shown in table B-3. This rainfall was applied to the 1.4-square mile upper basin and routed to the 0.4-square mile marsh.

Runoff information from this precipitation was developed using the Soil Conservation Service Curve Number method as described in the HEC-IFH User's Manual. A curve number of 62 was adopted, and considered representative of the drainage areas. Unit hydrograph data was developed using the SCS Dimensionless Unit graph method.

Developed runoff was routed through storage in the marsh with the HEC-IFH program. Storage capacity of the marsh area was determined by planimetering surface areas from 2-foot contour topographic mapping developed from aerial photography, dated December 1993. Discharge from the outlets was determined using Federal Highway Administration hydraulic design charts for highway culverts. The HEC-IFH uses these charts to determine outflow from the culverts based on headwater and tailwater conditions at the pipes. Runoff hydrographs from the watershed were routed through storage in the 0.4-square mile marsh to determine stage increase due to direct runoff at low and high tides. Table B-4 shows the increase in water surface elevation of the marsh for various selected frequencies, assuming the runoff occurs at spring high tide and a marsh water surface elevation of 4.0 feet NGVD. Plate B-5 shows the area-capacity relationship for the salt marsh area, as well as outlet rating curves for the existing 48 inch RCP culverts and the 1 percent chance (100-year) interior inflow and outflow.

7. TIDAL ANALYSIS

a. General. The Sagamore Salt Marsh is currently isolated from Cape Cod Canal by the Canal Service Road and Scusset Beach Road. Saltwater exchange to the marsh is limited by 4-foot diameter RCP culverts under each of these roads. Survey

TABLE B-4

INCREASES IN MARSH WATER SURFACE ELEVATION
FROM FRESHWATER RUNOFF
(Existing Conditions)

Frequency Event	Peak Inflow (cfs)	Stage Increase (ft)
10-year	90	0.3 *
50-year	200	0.7 *
100-year	230	0.8 *

* Runoff assumed with coincident Spring High Tide.

information has shown additional factors which may limit tidal interchange including the high invert of the main feeder channel, a negative slope of the channel between the culverts, and the high invert on the marsh side of the Canal Service Road culvert.

All flood elevations, area-capacity relationships, and other site characteristics are based on areal photogrammetric mapping (2-foot contours, dated December 1993) with supplemental topographic surveys performed in November 1994. The first part of the tidal analysis was to estimate a desired interior flood level which would restore as much of the marsh as possible without flooding homes, yards, septic systems, or wells. UNET, a hydraulic computer model, was then used to design culvert and channel configurations to obtain desired water elevations and proper drainage.

b. Flooding Impacts. Based on the surrounding topography and surveys completed in 1994, a proposed surface flood elevation of 4.8 feet NGVD in the marsh appears to have no adverse impact on any abutters. Surface water at this elevation will not inundate garages, homes, or yards, and roadways will not be overtopped. The homes adjacent to the marsh along Phillips Road have sill elevations above 5 feet NGVD, and most yard elevations are above 4.8 feet NGVD. The only yard elevations along Phillips Road below 4.8 feet NGVD are either not adjacent to the area of the marsh which will be impacted by increased tidal inundation or have higher ground elevations between them and the marsh.

To allow for conditions when freshwater runoff is coincident with high tides, tide elevations within the marsh should be limited to elevation 4.0 feet NGVD or lower for all predicted astronomic tides. This allows a minimum of 0.8 foot for surface water runoff storage, the estimated stage increase from a 100-year runoff event (see table B-4).

In addition, a groundwater analysis was performed by the USGS to characterize the existing groundwater system in the vicinity of Sagamore Marsh. The purpose of the analysis was to assess potential impacts of increased saltwater inundation of the wetlands on wells and residential septic systems using increased surface water levels estimated by this study. Refer to the "Groundwater" Appendix for a discussion of the groundwater analysis.

c. Selection of Computer Model. The hydraulic analysis of Sagamore Marsh was performed using a one-dimensional hydrodynamic model, UNET, the latest most advanced model readily available which would provide reasonably accurate results. UNET also has the capability to accurately model culverts using the Federal Highway Administration nomographs for determining hydraulic capacities of culverts. This model became available for Corps use through its Hydrologic Engineering Center in September 1992, and was updated in March 1993.

UNET can simulate one-dimensional unsteady flow through a full network of open channels. Stages are a function of channel geometry, and downstream backwater effects. UNET provides the user with the ability to apply flow and stage hydrographs, bridges, spillways, levee systems, and culverts. Cross sections are input in a modified HEC-2 forewater format. As mentioned previously, UNET also has the capability to develop culvert rating curves using inherent Federal Highway Administration nomographs. UNET has been successfully used by New England Division in several wetland restorations studies, including Leetes Island, Guilford, Connecticut and Galilee, Rhode Island.

Input needed to set up and run the UNET model includes topographic information and tide data.

(1) Topographic Surveys. Detailed surveying of the marsh was completed during November 1994 to provide information on the marsh topography. Detailed surveys were performed around the culverts and 1,300 feet into the marsh upstream from the culvert at the Canal Service Road. North of this point, cross sections were surveyed every 100 feet for a distance of 1,500 feet. Six major transects, surveyed across the marsh, are shown on plate B-6 (transect 3 was not used in the hydraulic analysis, and is not shown on plate B-6).

As part of the survey effort, four staff gages were installed. Gage 1 was located in Cape Cod Canal on the fishing pier at Scusset Beach, gage 2 between the two culverts, gage 3 at the end of the riprap-lined channel, and gage 4 in the middle of the marsh, at surveyed transect 2. Gage locations are shown on plate B-6.

(2) <u>Tide Data</u>. Tidal monitoring data was collected to describe the existing salt marsh tidal regime, and to obtain information to calibrate a model of one dimensional flow. NED personnel collected tide data at four gages on December 5, 1994. Tidal data collected were referenced to National Geodetic Vertical Datum (NGVD) to allow correlation with the nearest NOS gage in Boston, Massachusetts. The correlation allows NED to assign important statistical tidal datum planes to the Sagamore Marsh, based on historic data collected at the Boston gage (see table B-1). These relationships are the basis for predictive analysis completed for the Sagamore Marsh. Collected tidal data was used to document movement of the tidal prism into and out of the marsh, and provide background information for the numerical model representation of the marsh. Analysis of the data shows that the marsh, under its current condition, with two 4-foot diameter culverts, never drains during low tide conditions. This is a result of the elevated invert of the Cape Cod Canal Service Road culvert, the negative slope of the channel between the culverts, and the high invert of the feeder channel to the marsh. In addition, the culverts are undersized for the volume of the marsh, and restrict flows into and out of it.

Nine hours of tide data were measured for use in calibrating the numerical model to be used to analyze the effects of the proposed culverts. On 5 December 1995, the tide in Cape Cod Canal ranged from -5.4 to 6.6 feet NGVD. This tide range of approximately 12 feet is greater than a mean spring tide condition (9.0 feet), and almost equal to the estimated maximum predicted tide range which can occur at the site (approximately 12.4 feet.). The high tide elevation measured was just above the maximum predicted astronomical high water for the site (6.5 feet NGVD).

(3) <u>Model Calibration</u>. Water surface elevations, measured on December 5, 1994, were used to calibrate the UNET model. These measurements were completed over a 9-hour period to ensure that both incoming and outgoing tidal characteristics would be represented and compared.

Tidal measurements from the Scusset Beach fishing pier in the Cape Cod Canal (gage 1) were used as boundary conditions for the calibration simulation. In addition, tidal water surface levels for the preceding two days, estimated from tidal conditions at Boston, were used to provide data for startup of the finite difference model.

Cross sectional information, used as input to the model, was obtained from 1994 surveys and from 2-foot contour maps of the marsh. Manning's frictional "n" values (ranging from 0.07 in the channel to 0.12 in the overbanks), estimated by comparing vegetation and topography of the site with "n" values associated with Chow's Open Channel Hydraulics, were adjusted and minor changes made to the cross sections so results more closely matched observed tide level measurements. Minor changes to the estimated cross section overbank areas are justified since changes affected less than 10 percent of the wetted ditch area. In addition, an increased storage parameter was added to the modelled version to account for side channel storage.

Results of the calibration run for December 5, 1994 are shown on plates B-7 through B-9. As can be seen, computed results match very favorably to the observed data, with computed levels only a few tenths of a foot or less different from the observed at all times. Based on the good fit to observed data, the model was considered to be calibrated to the degree needed for accurate predictive results.

(4) Model Verification. Water surface elevations, measured over a full cycle at gage 1 on 13 July, 1995, were input as the boundary condition into the UNET model. The tide range on 13 July was 10.85 feet. Spot readings were taken on the same day at gages 2 and 3, and at transect 2 for verification of the UNET model. Table B-5 shows measured and computed elevations at high and low tide.

TABLE B-5

VERIFICATION RUN
13 JULY 1995
(Feet NGVD)

	Gage 2		Gage 3		T2	
	Measured	Computed	Measured	Computed	Measured	Computed
High	3.53	3.50	3.05	2.96	2.59	2.77
Low	0.03	0.11	1.09	1.07	1.50	1.36

As can be seen, computed high and low elevations match those measured within two-tenths, which verified the accuracy of the model indicated by calibration.

d. Restoration of Tidal Flows

(1) General. The intent of modelling was to predict culvert sizes needed to provide sufficient saltwater exchange to

restore as much of the marsh as possible, without adversely affecting yards, homes, and septic systems, or water quality of water supply wells. Based on data presented previously in section 7b, the maximum water surface elevation which should provide no surface flooding to the abutters is estimated at 4.8 feet NGVD, which includes approximately 0.8-foot allowance for freshwater runoff. Therefore, to allow sufficient storage for interior freshwater runoff, water levels caused by tidal flooding should be kept to about 4.0 feet NGVD, or less. Enlarging the existing culverts has the disadvantage of making the marsh area more susceptible to tidal flooding during coastal storms and hurricanes. Therefore, for any proposed culvert plan, control structures must be provided and operated, either automatically or manually, during times of unusual tidal flood events. Because of the uncertainty associated with manual operation, automatic tide gates are recommended for this site. Additional backup gates or methods of closure should also be provided should the automatic gates fail.

(2) Results. The existing 48-inch diameter culvert under the Canal Service Road has an invert of -2.71 in the Cape Cod Canal, and an invert of -2.05 in the feeder channel to the marsh. The 48-inch culvert under Scusset Beach Road has an invert on the canal side of -2.71 feet NGVD, and -2.45 feet NGVD on the marsh side. The channel invert elevation varies from -2.0 to 0.55 feet NGVD from the culvert at the canal to the end of the riprap, with the elevation near the Scusset Beach Road culvert at -1.0 feet NGVD.

An analysis was performed to evaluate alternatives including a) lowering channel and culvert inverts to improve drainage, and b) increasing the existing culvert opening and channel width to increase tidal inundation of the marsh. The desired configuration would be a balance of flooding to maximize salt marsh restoration, enough drainage to allow for the restoration without causing permanent flooding, and economic reasonableness.

The first set of alternatives used the existing culvert inverts with a larger culvert, and analyzed the effect of lowering the channel invert to -4.0 feet NGVD. For comparison, alternatives were run dredging the channel to the end of the riprap, to surveyed transects 1, and 2. An arbitrarily sized 10- by 20-foot box culvert, and a tide range occurring approximately two times per month, were used to compare impacts of the change in dredging. Results, computed at surveyed transect 2, are shown in plate B-10. Results were analyzed at transect 2 because that location is close to the middle of the marsh, and water surface elevations, estimated from actual measurements and computer analysis, seem to level out past that point. As can be seen, height of the water during high tide conditions is increased approximately 0.20 feet for all three dredged channel alternatives. Dredging does not produce a lower water surface elevation in the middle of the marsh at low tide until the channel has been deepened up to transect 2. Benefits of this lowered channel invert elevation are minimal compared to the cost and environmental impact associated with dredging to transect 2. At this stage, the alternative of keeping the existing culvert and channel inverts was selected as the preliminary design condition.

Other alternatives were analyzed in an attempt to attain better drainage at low tide within the marsh. The alternatives included lowering inverts of the culverts, in combination with dredging of the upstream channel. For all alternatives, the canal side invert of the Canal Service Road culvert remained at -2.71 feet NGVD, the marsh side was lowered to -2.45 feet NGVD, and the Scusset Beach Road culvert was leveled out to -2.45 feet NGVD. The channel between the two culverts would be dredged to -2.45 feet NGVD. The first alternative involved dredging from the Scusset Beach Road culvert to the end of the riprap to maintain a constant slope. In the second alternative, dredging would continue to transect 1, and in the third, dredging would continue to transect 2. For all three alternatives, one 6- by 16-foot box culvert was used with a tide range occurring approximately two times per month. Plate B-11 shows results of the invert evaluations, which indicate that levels are raised about 0.10 foot at high tide for all alternatives. Drainage is improved by 0.5 foot by maintaining all culvert inverts at -2.45 feet NGVD. Also, as shown in plate B-11, significantly improved drainage is not obtained at transect 2 until the dredging has reached that point. The alternative of installing the Canal Service Road culvert with invert elevations of -2.71 feet NGVD on the Canal side and -2.45 feet NGVD on the marsh side, installing the Scusset Beach Road culvert level at -2.45 feet NGVD, dredging the channel between them to -2.45 feet, and dredging to the end of the riprap to maintain a constant slope was selected as the design condition.

After establishing the channel and culvert invert elevations, numerous culvert and channel width alternatives were analyzed in detail to determine one which would meet requirements of the desired marsh regime. The seven alternatives, shown in table B-6, were simulated using a tide range with a frequency of occurrence of approximately eight times per month (frequency necessary to restore salt marsh). Plate B-12 presents results, at transect 2, for some culverts considered for the marsh. As can be seen, the estimated high tide of 4.95 feet NGVD in the Cape Cod Canal, produced high tide levels, ranging from approximately 2.9 to 3.7 feet NGVD in the middle of the marsh for culvert sizes ranging from one 4-foot diameter culvert (existing) to two 10- by 20-foot box culverts (under each road). A 6-foot minimum height was used in all proposed alternatives to utilize as much of the 7.9-foot mean tide range as possible. The highest incremental increase occurs between the existing conditions and the 6- by 6-foot box culvert.

TABLE B-6

CULVERT AND CHANNEL ALTERNATIVES

Alternative	Configuration
1	6'H X 6'W culvert, 6' bottom width
2	6'H X 8'W culvert, 8' bottom width
3	6'H X 12'W culvert, 12' bottom width
4	6'H X 16'W culvert, 16' bottom width
5	10'H X 20'W culvert, 30' bottom width
6	6'H X 40'W culvert, 40' bottom width
7	10'H X 40'W culvert, 40' bottom width

A cost-benefit analysis, shown in the Incremental Analysis, indicated that sufficient environmental benefits could be obtained with a box culvert size of 6- by 12-foot under each road. The increase in high tide elevation from the existing 48-inch culvert to a 6- by 12-foot box culvert of approximately 0.4 foot at transect 2, would allow enough tidal inundation to restore approximately 50 acres of salt marsh. This culvert was selected for final design.

Using the selected 6- by 12-foot culvert and water surface elevation at 3.2 ft-NGVD developed runoff was routed through storage in the 0.4 square mile marsh with the HEC-IFH program, as specified in paragraph 5. It was determined that changes in stage increase was negligible from the ones specified in table B-4.

At this point, with the 6- by 12-foot culvert selected, the option of widening the existing channel to obtain higher water levels at high tide was evaluated. It was assumed that widening would take place to the end of the existing riprap. This alternative was evaluated in the middle of the marsh, at transect 2; model results are shown in plate B-13. The difference in water surface elevations at high tide between the 12-foot wide channel (proposed to accommodate the culvert) and a 30-foot wide channel is less than 0.10 foot. This increase was not considered substantial enough to warrant the additional cost and environmental impact associated with channel widening.

proposed structure were to remain in the open position, to emphasize the importance of operation of the gates, as well as providing a backup set of sluice gates or stoplogs. Estimated 10-, 50-, and 100-year floods with high tides in the Cape Cod Canal of 8.3, 9.9, and 10.4 feet NGVD, respectively, were simulated for both existing and proposed conditions, and are presented in plates B-14 through B-16. Under existing conditions, the tide level will climb to approximate elevation 3.3 feet NGVD for a 10-year storm, and 3.4 for a 50- and 100-year storm in the middle of the marsh, which is less than the estimated damage level of 4.0 feet NGVD. However, under the proposed condition, the interior tide level near the potential damage area will rise to elevations 4.1, 4.3 and 4.5 feet NGVD for 10-, 50-, and 100-year events, respectively. These elevations are above the estimated damage level. Water levels at transect 4, closest to low-lying properties, for 10, 50, 100-year events are less than 0.10 feet lower than those shown at transect 2. Plate B-16a shows 100-year water levels at transect 4.

7. SUMMARY

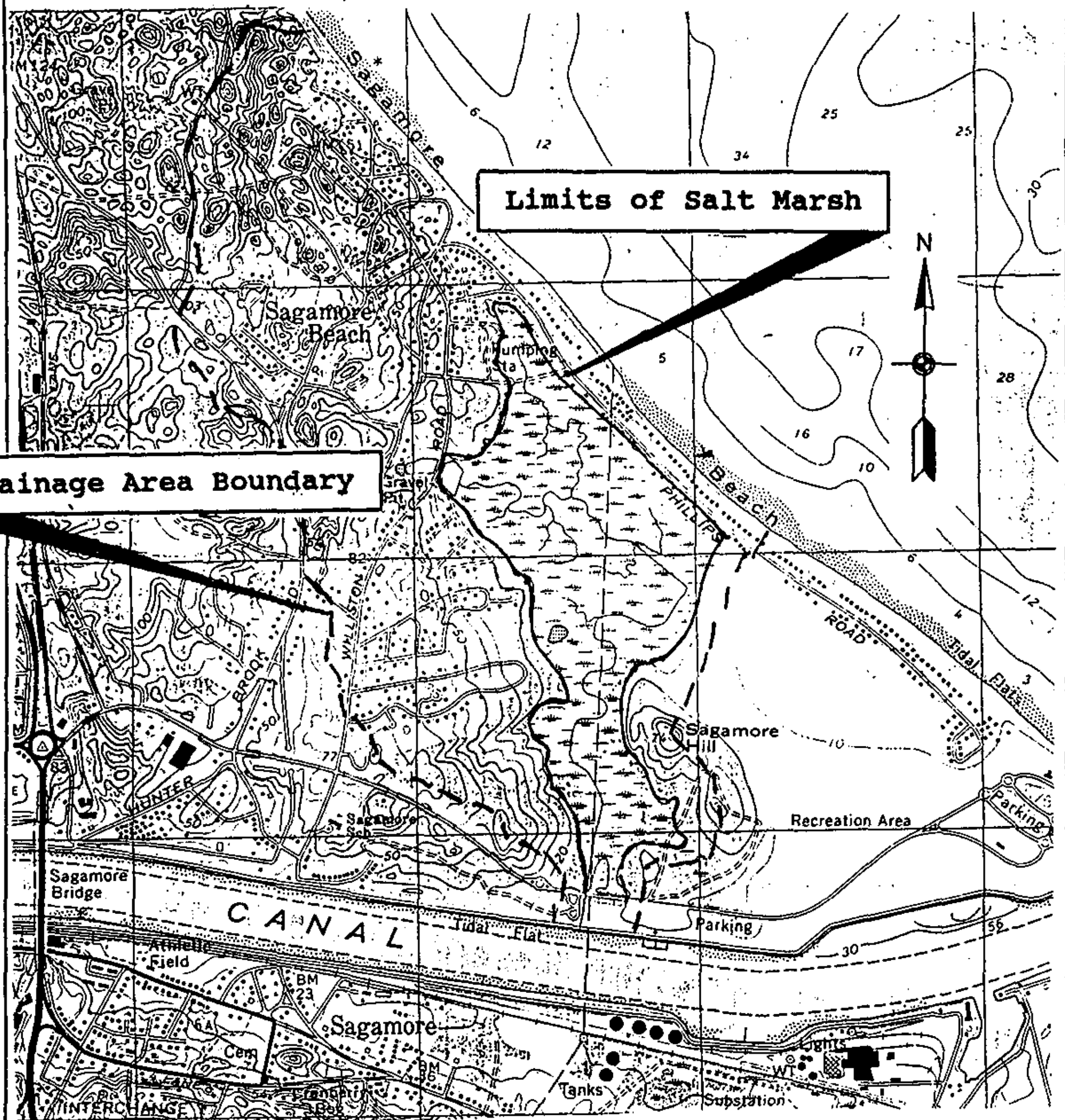
This report provides the hydrologic and hydraulic assessment of existing conditions in the Sagamore Marsh as well as predicted conditions after installation of the proposed culverts.

Using the Corps computer program HEC-IFH, runoff from the uncontrolled drainage area was routed into the Sagamore Marsh and combined with the direct rainfall onto the marsh. Rainfall runoff analysis was performed to determine the increase in stages due to direct rainfall on the marsh and freshwater runoff into the marsh.

The maximum water surface elevation, which should have no adverse impacts to abutters, is estimated to be 4.8 feet NGVD, which includes approximately 0.8 foot allowance for direct rainfall and freshwater runoff. Therefore, to allow sufficient storage for interior freshwater runoff, water levels caused by tidal flooding should be kept lower than 4.0 feet NGVD for non-storm conditions.

Based on hydrologic analysis completed, and using the Corps one-dimensional hydrodynamic model "UNET", this analysis recommends installation of a 6- by 12-foot culvert under the Canal Service Road and Scusset Beach Road, with some dredging and widening up to the end of the existing riprap, installation of automatic tide gates or sluice gates for primary control and installation of sluice gates or stoplogs for backup control. The invert of the culvert beneath the Canal Service Road will be at elevation -2.71 feet NGVD on the canal side, and -2.45 feet NGVD on the interior side. The Scusset Beach Road culvert will be placed level with an invert elevation of -2.45 feet NGVD.

Based on the analysis completed, one 6- by 12-foot box culvert under each road will be sufficient to flood enough of the marsh to restore approximately 50 acres without causing flooding of homes and roads, provided gates are used to control inflows to the marsh for water levels which are greater than astronomic.



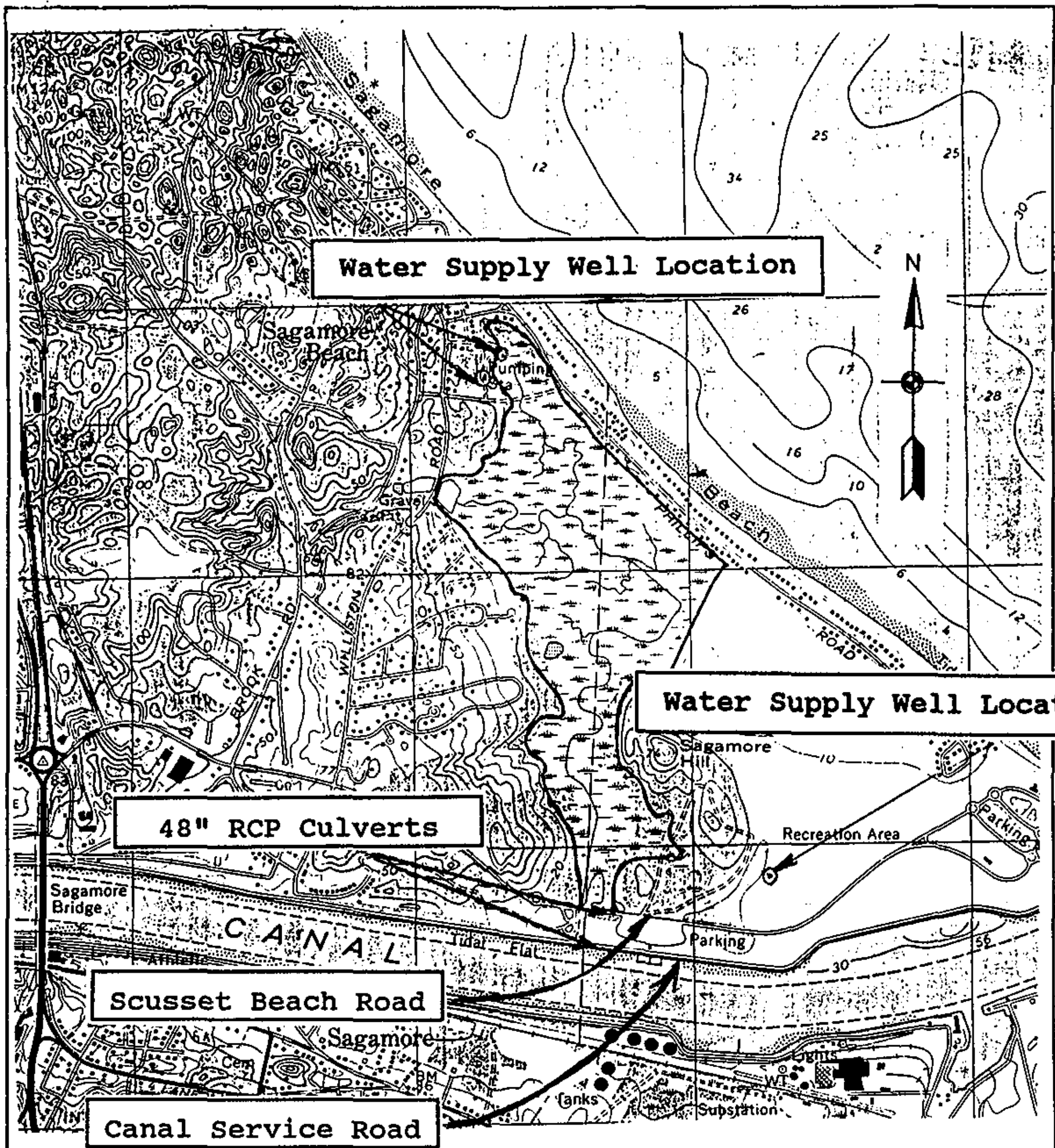
SCALE: 1" = 2100'

SAGAMORE MARSH RESTORATION
FEASIBILITY STUDY
Sandwich/Bourne, Massachusetts

DRAINAGE AREA

HEB **June 1995**

PLATE B-1



SCALE: 1" = 2100'

SAGAMORE MARSH RESTORATION
FEASIBILITY STUDY
Sandwich/Bourne, Massachusetts

LOCATION MAP

HEB **June 1995**

PLATE B-2

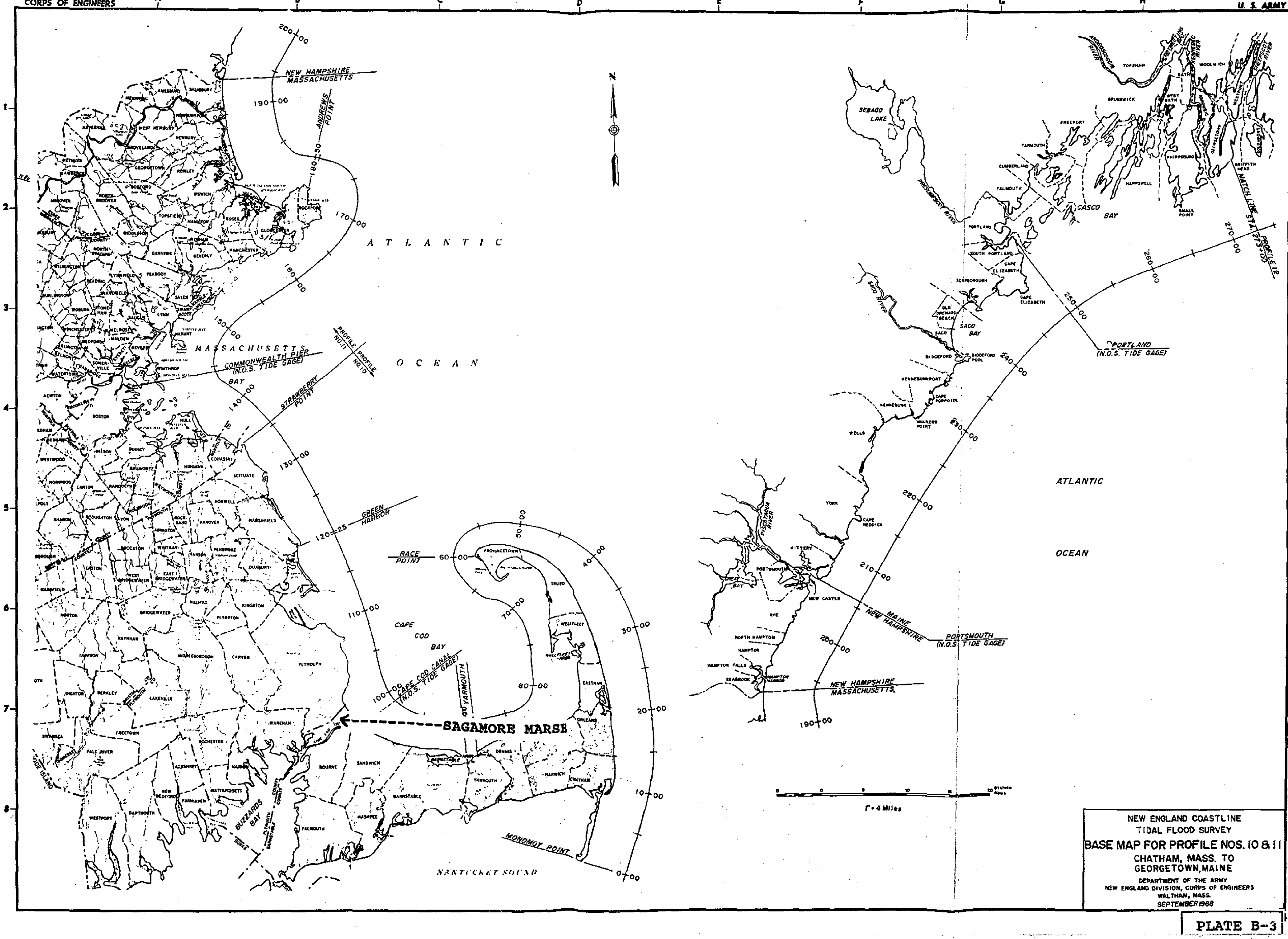

CORPS OF ENGINEERS
U. S. ARMY
ATLANTIC
OCEAN
MASSACHUSETTS
NEW HAMPSHIRE
MASSACHUSETTS
ANDREWS POINT
COMMONWEALTH PIER
(N.O.S. TIDE GAGE)
BAY
PROFILE NO. 11
PROFILE NO. 10
STRAWBERRY POINT
GREEN HARBOR
RACE POINT
CAPE COD BAY
CAPE COD CANAL
(N.O.S. TIDE GAGE)
YARMOUTH
SAGAMORE MARSH
BUZZARDS BAY
MONOMOY POINT
NANTUCKET SOUND
SEBAGO LAKE
CASCO BAY
PORTLAND
(N.O.S. TIDE GAGE)
SACO BAY
MAINE
NEW HAMPSHIRE
PORTSMOUTH
(N.O.S. TIDE GAGE)
NEW HAMPSHIRE
MASSACHUSETTS
MATCH LINE STA. 273+00
PROFILE 12
1" = 4 Miles
NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY
BASE MAP FOR PROFILE NOS. 10 & 11
CHATHAM, MASS. TO
GEORGETOWN, MAINE
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1968

PLATE B-3

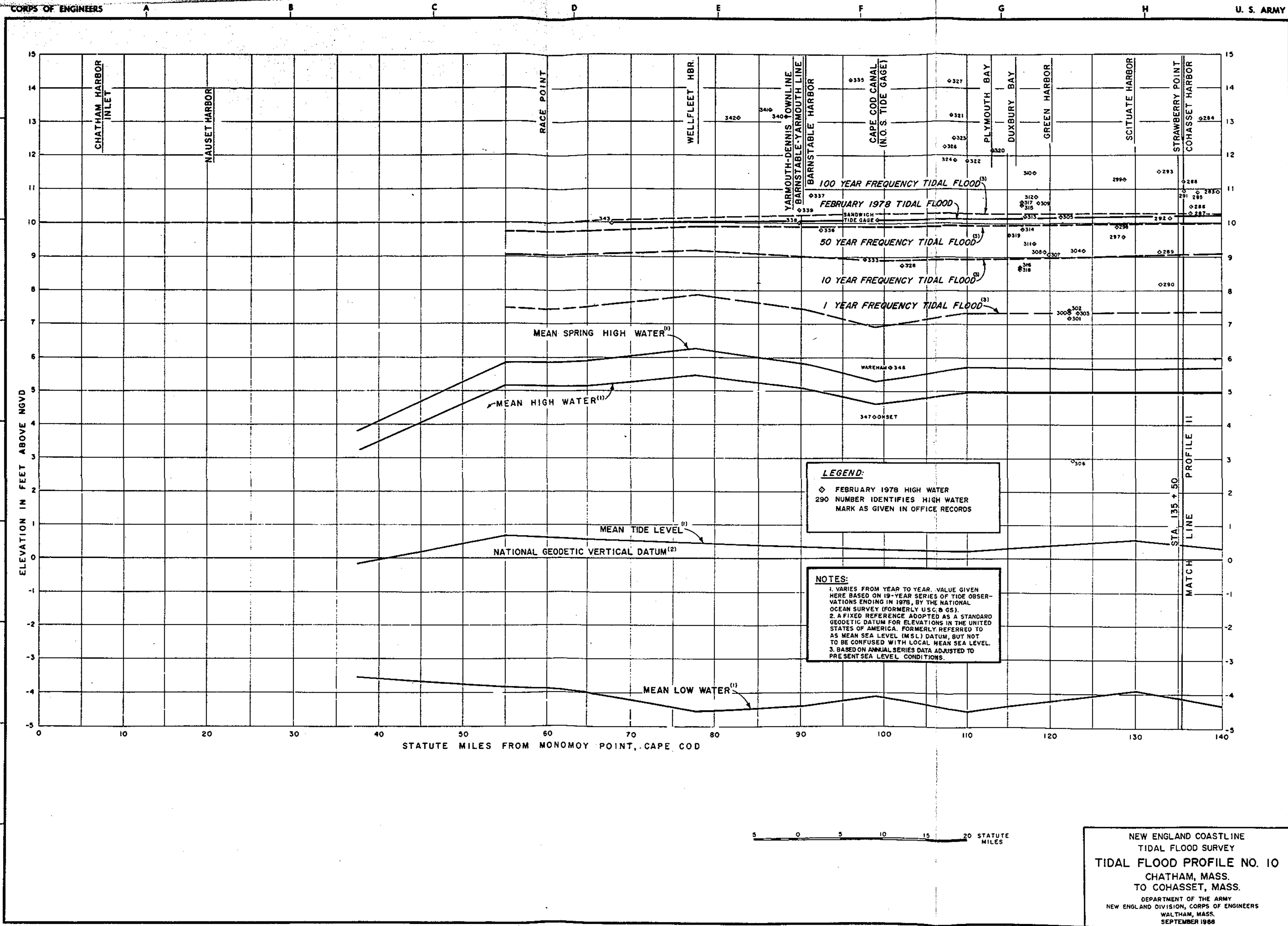
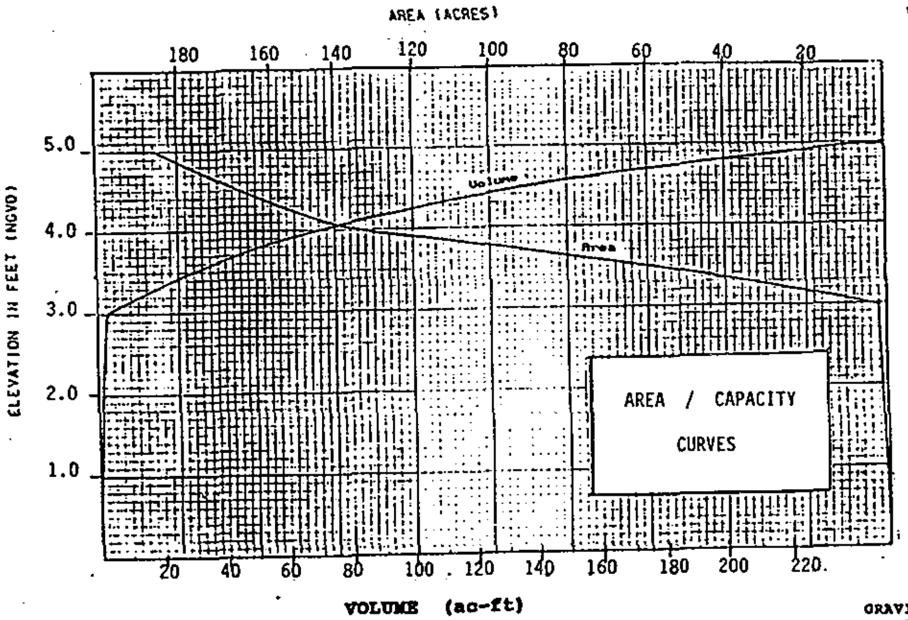
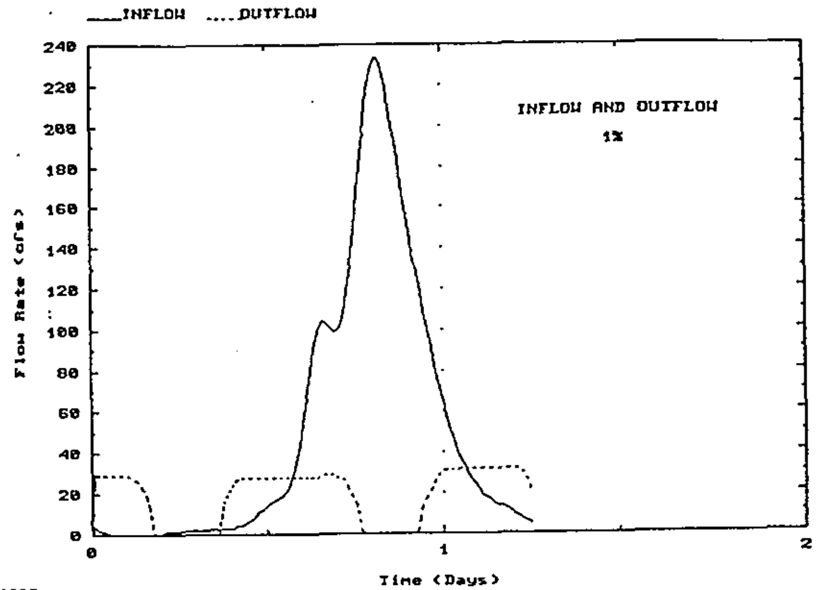
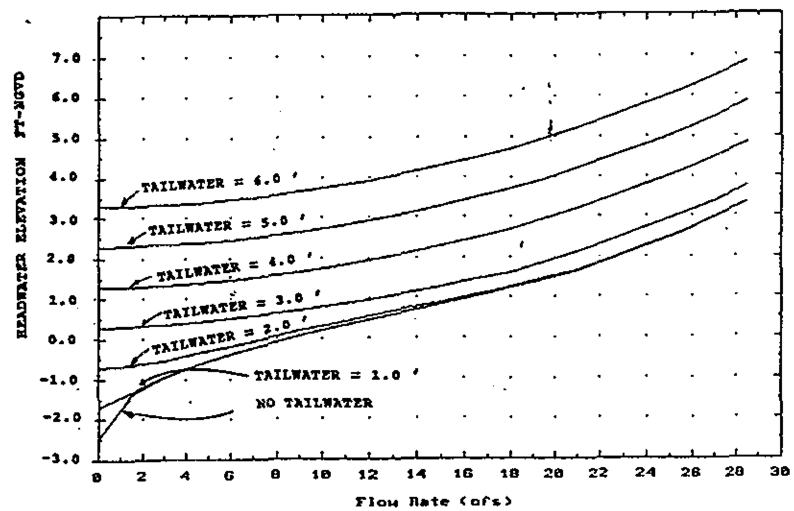

CORPS OF ENGINEERS
U. S. ARMY
CHATHAM HARBOR INLET
NAUSET HARBOR
RACE POINT
WELLFLEET HBR.
YARMOUTH-DENNIS TOWNLINE
BARNSTABLE-YARMOUTH LINE
BARNSTABLE HARBOR
CAPE COD CANAL (N.O.S. TIDE GAGE)
PLYMOUTH BAY
DUXBURY BAY
GREEN HARBOR
SCITUATE HARBOR
STRAWBERRY POINT
COHASSET HARBOR
100 YEAR FREQUENCY TIDAL FLOOD(3)
FEBRUARY 1978 TIDAL FLOOD
SANDWICH TIDE GAGE
50 YEAR FREQUENCY TIDAL FLOOD(3)
10 YEAR FREQUENCY TIDAL FLOOD(3)
1 YEAR FREQUENCY TIDAL FLOOD(3)
MEAN SPRING HIGH WATER(1)
WAREHAM
MEAN HIGH WATER(1)
ONSET
MEAN TIDE LEVEL(1)
NATIONAL GEODETIC VERTICAL DATUM(2)
MEAN LOW WATER(1)
ELEVATION IN FEET ABOVE NGVD
STATUTE MILES FROM MONOMOY POINT, CAPE COD
MATCH LINE STA 135 + 50 PROFILE 11
LEGEND:
◇ FEBRUARY 1978 HIGH WATER
290 NUMBER IDENTIFIES HIGH WATER MARK AS GIVEN IN OFFICE RECORDS
NOTES:
1. VARIES FROM YEAR TO YEAR. VALUE GIVEN HERE BASED ON 19-YEAR SERIES OF TIDE OBSERVATIONS ENDING IN 1978, BY THE NATIONAL OCEAN SURVEY (FORMERLY U.S.C.& G.S.).
2. A FIXED REFERENCE ADOPTED AS A STANDARD GEODETIC DATUM FOR ELEVATIONS IN THE UNITED STATES OF AMERICA. FORMERLY REFERRED TO AS MEAN SEA LEVEL (MSL) DATUM, BUT NOT TO BE CONFUSED WITH LOCAL MEAN SEA LEVEL.
3. BASED ON ANNUAL SERIES DATA ADJUSTED TO PRESENT SEA LEVEL CONDITIONS.
STATUTE MILES
NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY
TIDAL FLOOD PROFILE NO. 10
CHATHAM, MASS.
TO COHASSET, MASS.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988

PLATE B-4





GRAVITY OUTLET RATING TABLE
EXISTING CONDITIONS



SAGAMORE MARSH RESTORATION
FEASIBILITY STUDY

Sandwich/Bourne, Massachusetts

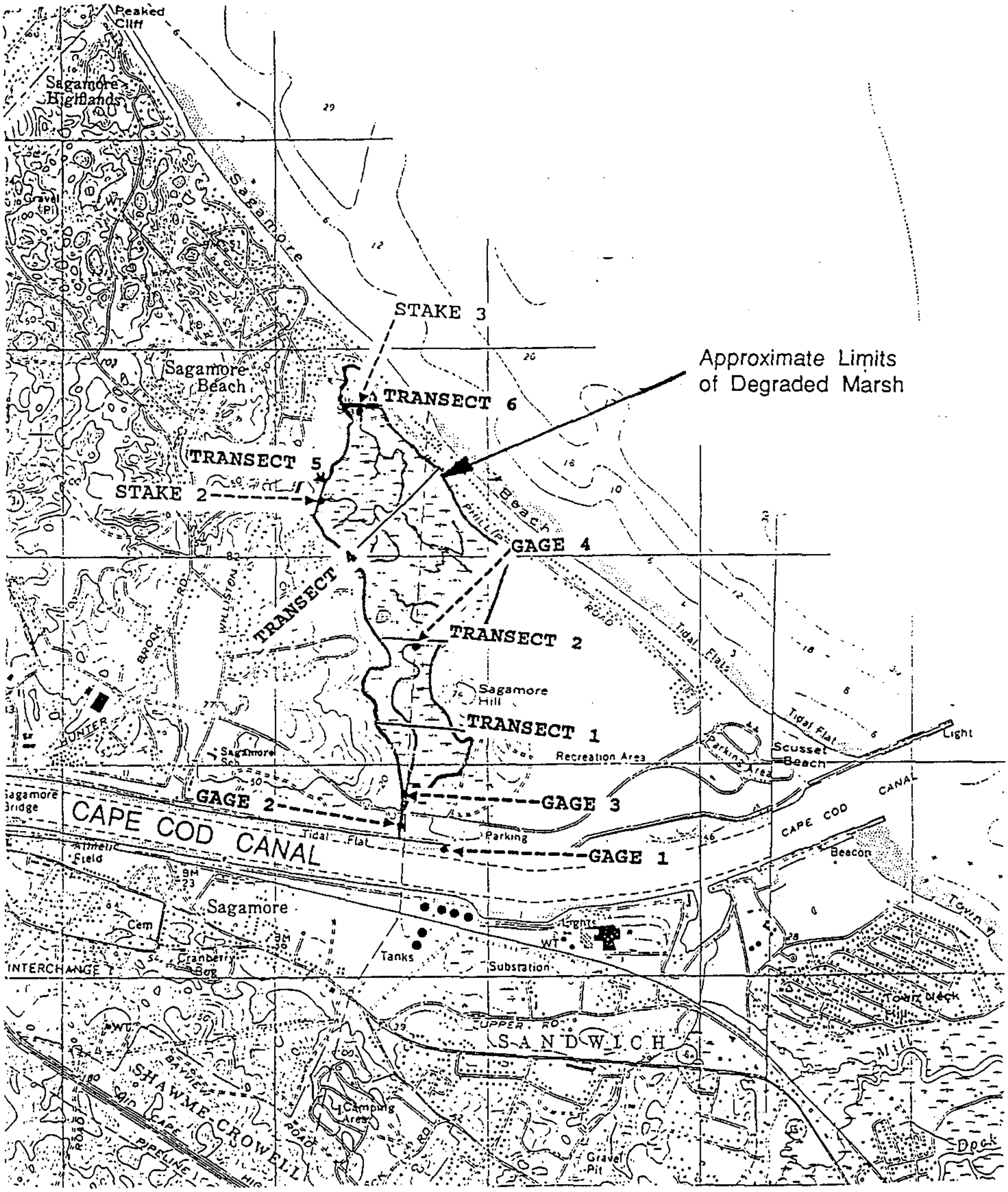
INTERIOR HYDROLOGY

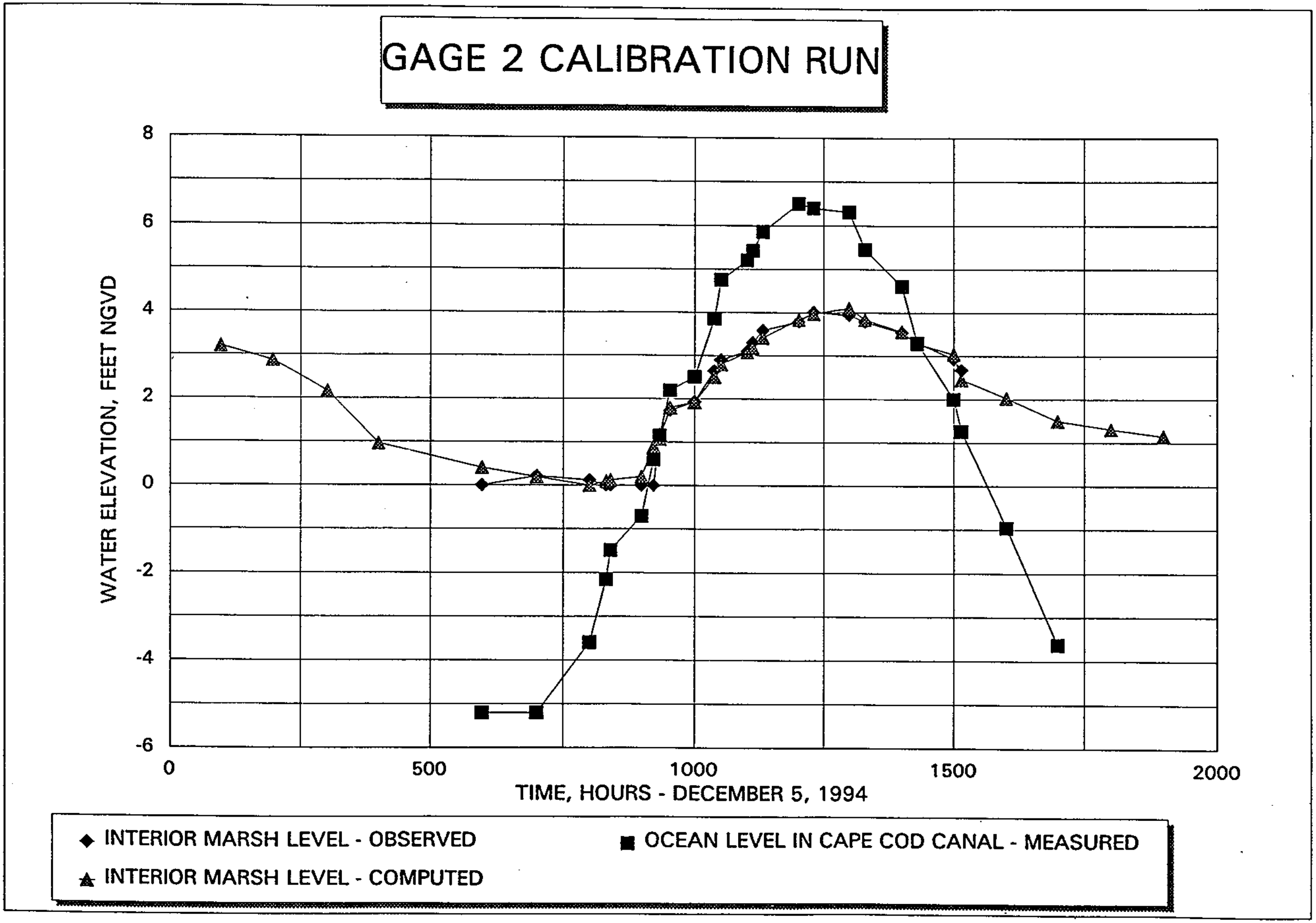
IIEB June 1996

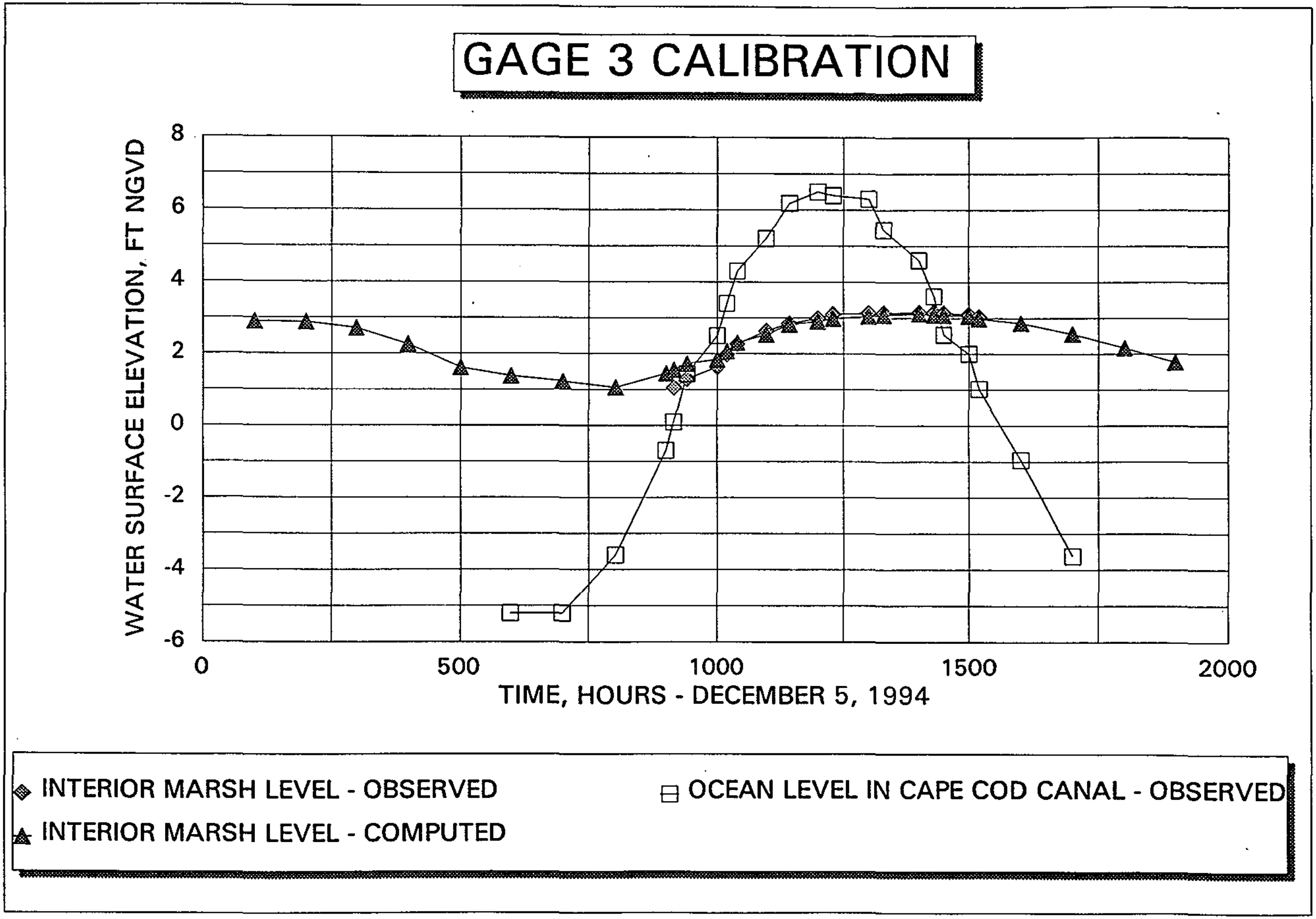
PLATE B-5

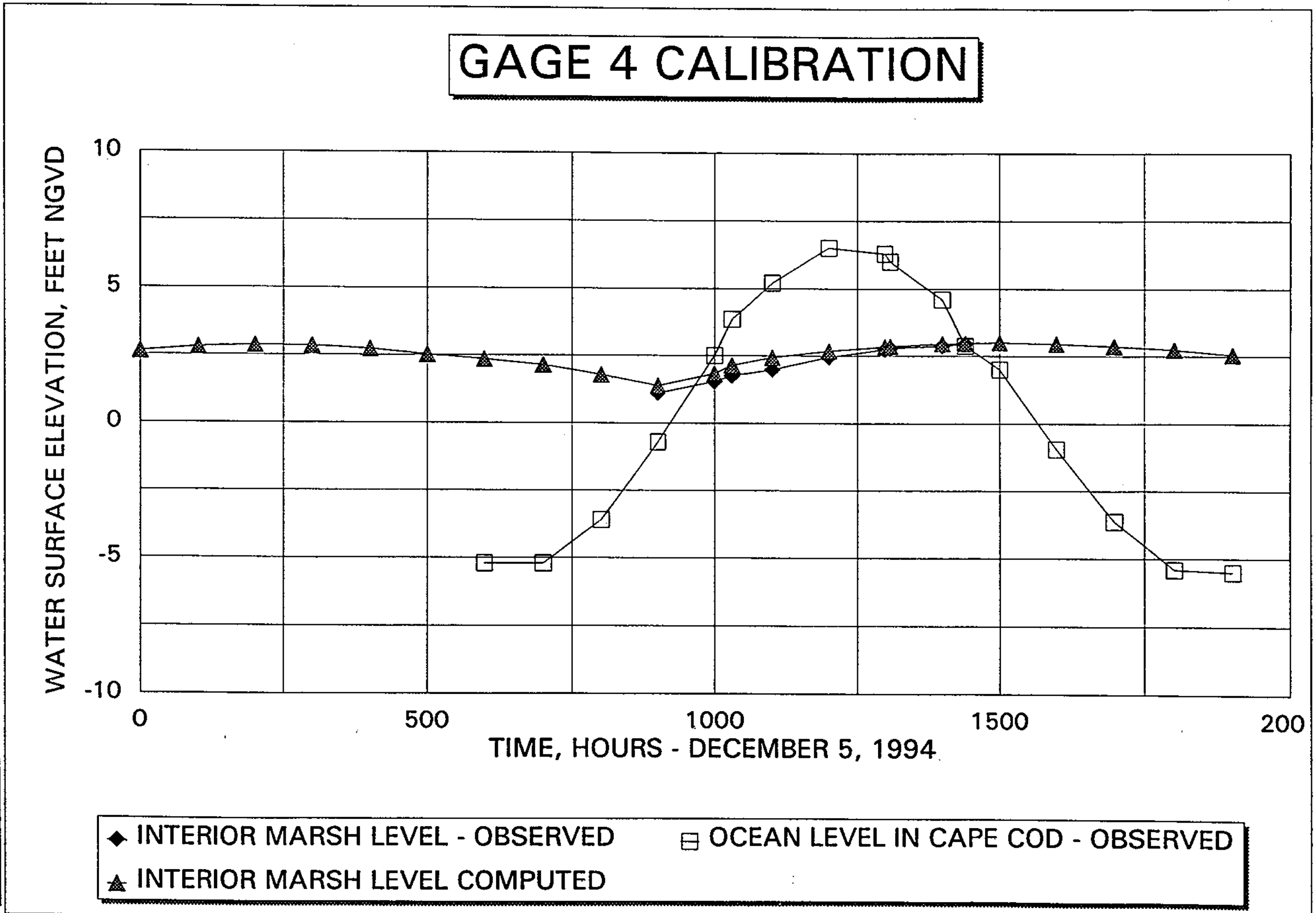
SAGAMORE MARSH RESTORATION

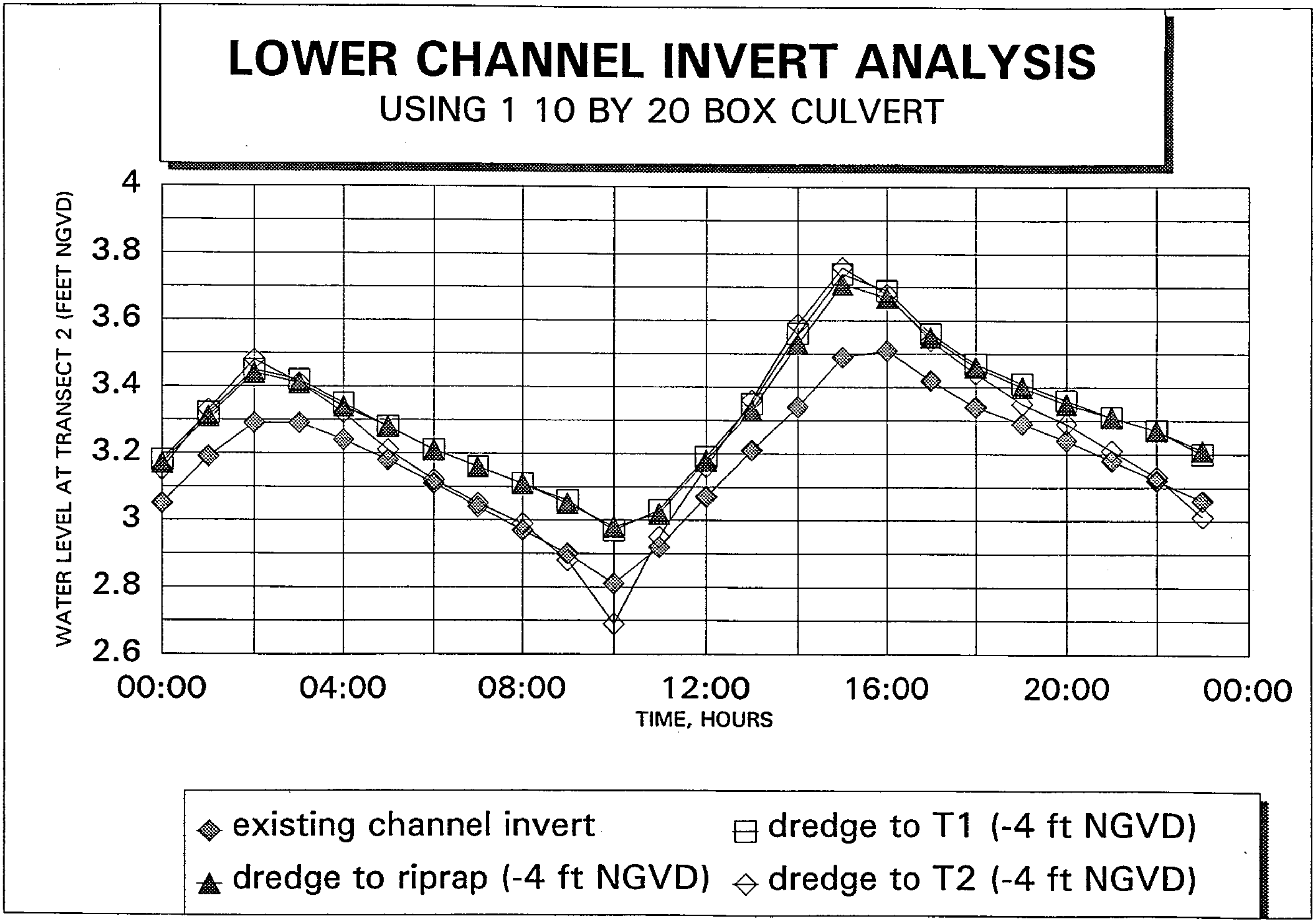
LOCATIONS OF TRANSECTS, TIDE GAGES, AND STAKES

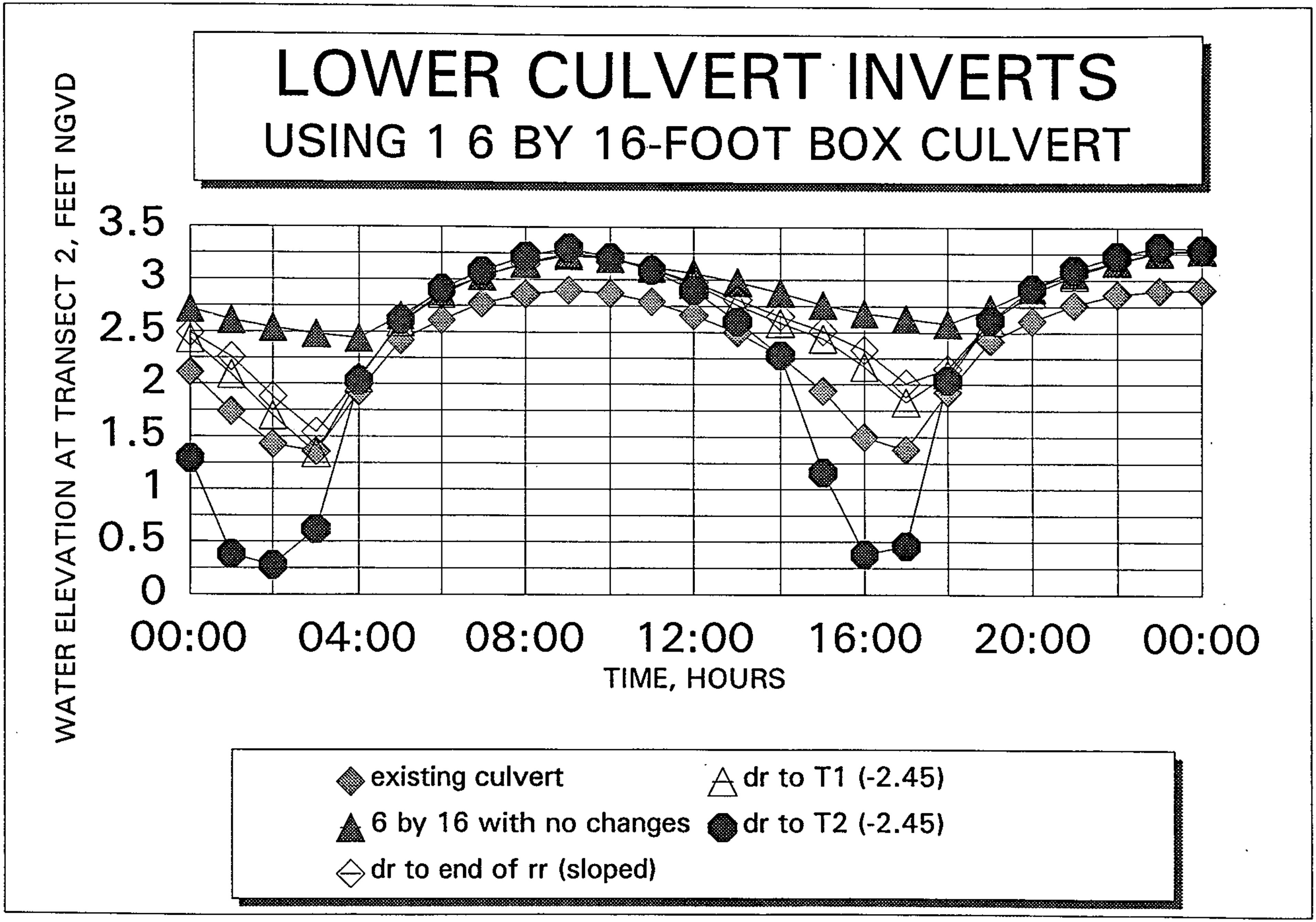


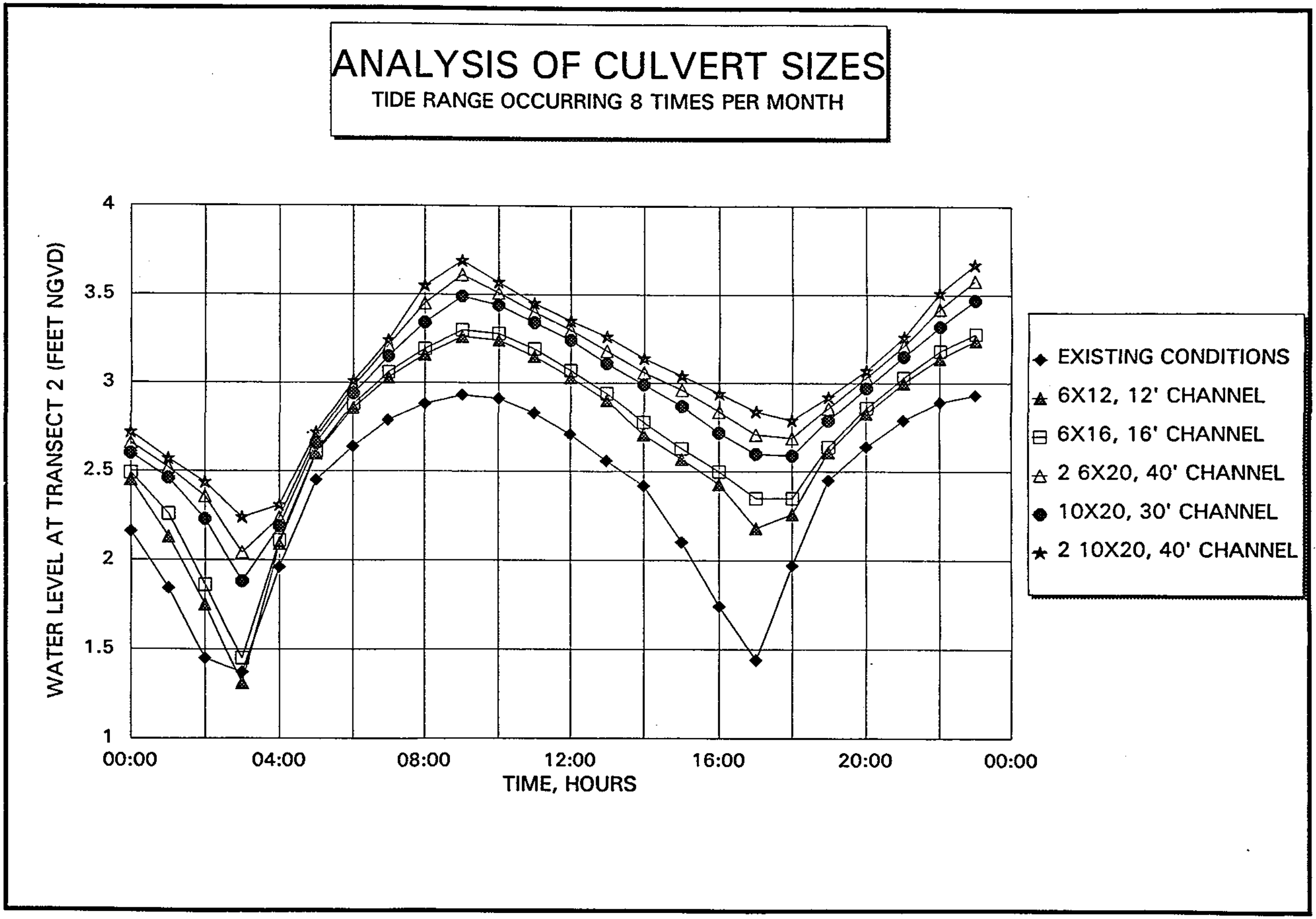

GAGE 2 CALIBRATION RUN
WATER ELEVATION, FEET NGVD
8
6
4
2
0
-2
-4
-6
0
500
1000
1500
2000
TIME, HOURS - DECEMBER 5, 1994
INTERIOR MARSH LEVEL - OBSERVED
INTERIOR MARSH LEVEL - COMPUTED
OCEAN LEVEL IN CAPE COD CANAL - MEASURED

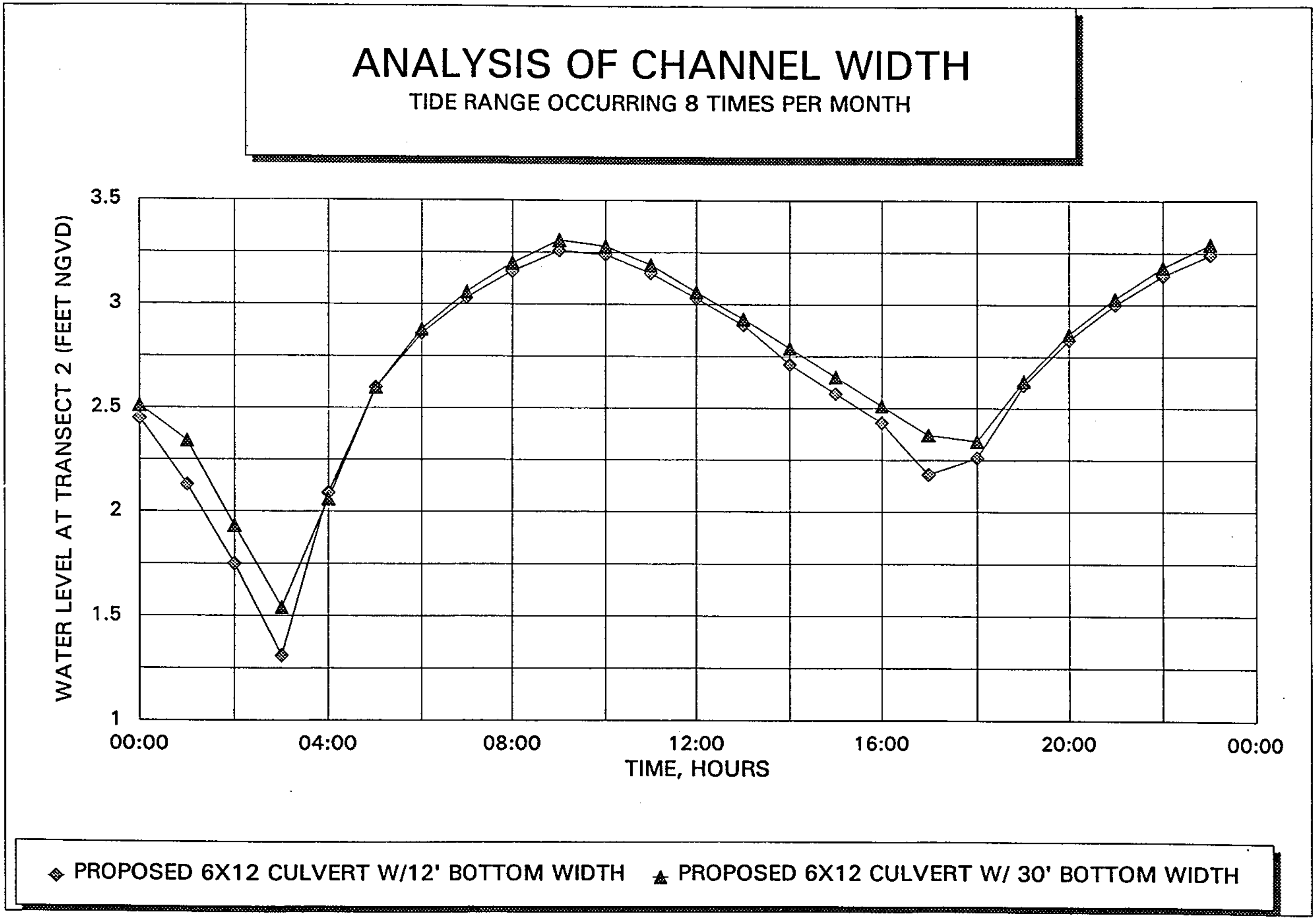

GAGE 3 CALIBRATION
WATER SURFACE ELEVATION, FT NGVD
8
6
4
2
0
-2
-4
-6
0
500
1000
1500
2000
TIME, HOURS - DECEMBER 5, 1994
INTERIOR MARSH LEVEL - OBSERVED
INTERIOR MARSH LEVEL - COMPUTED
OCEAN LEVEL IN CAPE COD CANAL - OBSERVED

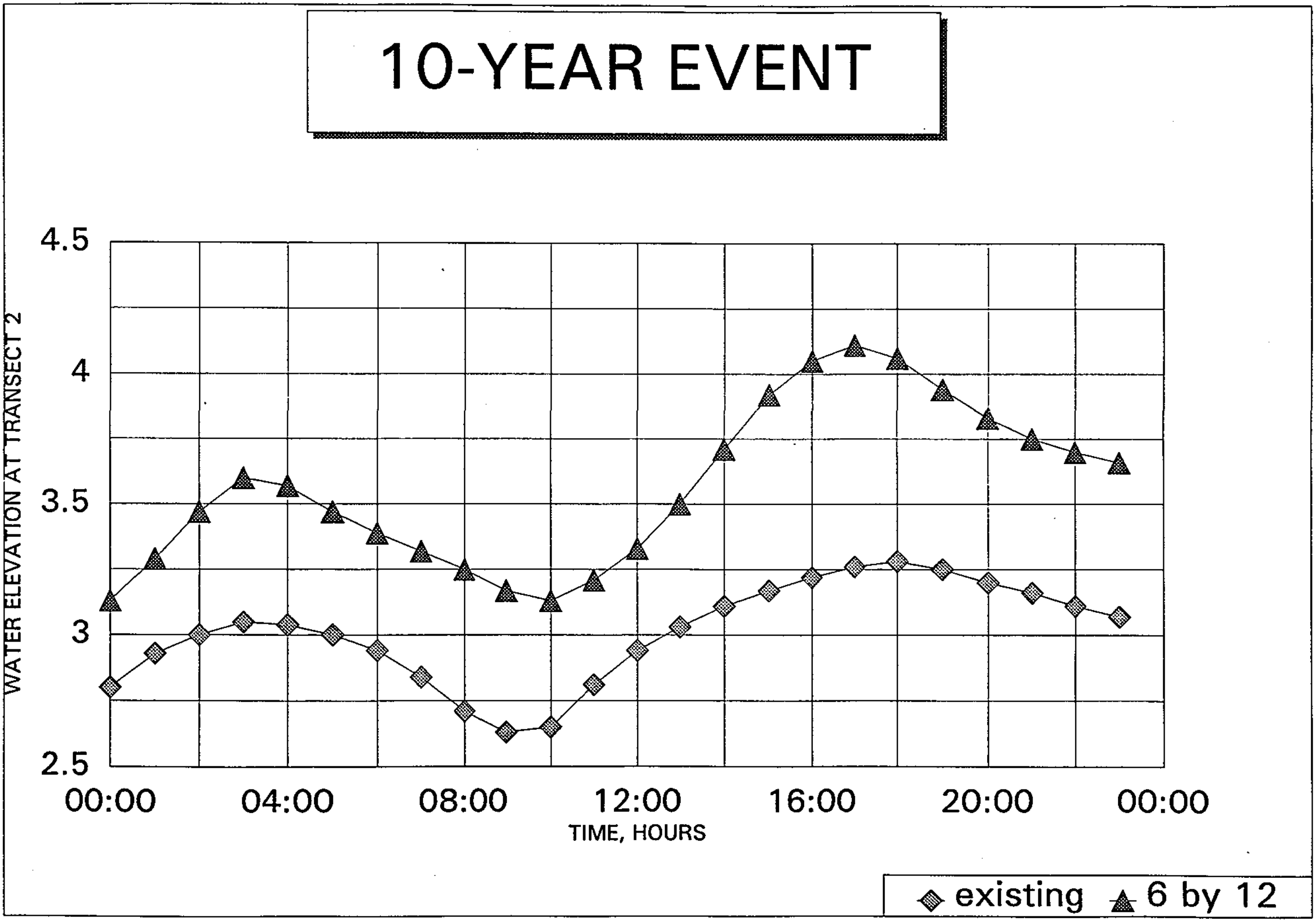

GAGE 4 CALIBRATION
WATER SURFACE ELEVATION, FEET NGVD
10
5
0
-5
-10
0
500
1000
1500
200
TIME, HOURS - DECEMBER 5, 1994
INTERIOR MARSH LEVEL - OBSERVED
OCEAN LEVEL IN CAPE COD - OBSERVED
INTERIOR MARSH LEVEL COMPUTED


LOWER CHANNEL INVERT ANALYSIS
USING 1 10 BY 20 BOX CULVERT
WATER LEVEL AT TRANSECT 2 (FEET NGVD)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing channel invert
dredge to T1 (-4 ft NGVD)
dredge to riprap (-4 ft NGVD)
dredge to T2 (-4 ft NGVD)


LOWER CULVERT INVERTS
USING 1 6 BY 16-FOOT BOX CULVERT
WATER ELEVATION AT TRANSECT 2, FEET NGVD
3.5
3
2.5
2
1.5
1
0.5
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing culvert
6 by 16 with no changes
dr to end of rr (sloped)
dr to T1 (-2.45)
dr to T2 (-2.45)


ANALYSIS OF CULVERT SIZES
TIDE RANGE OCCURRING 8 TIMES PER MONTH
WATER LEVEL AT TRANSECT 2 (FEET NGVD)
4
3.5
3
2.5
2
1.5
1
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
EXISTING CONDITIONS
6X12, 12' CHANNEL
6X16, 16' CHANNEL
2 6X20, 40' CHANNEL
10X20, 30' CHANNEL
2 10X20, 40' CHANNEL


ANALYSIS OF CHANNEL WIDTH
TIDE RANGE OCCURRING 8 TIMES PER MONTH
WATER LEVEL AT TRANSECT 2 (FEET NGVD)
3.5
3
2.5
2
1.5
1
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
PROPOSED 6X12 CULVERT W/12' BOTTOM WIDTH
PROPOSED 6X12 CULVERT W/ 30' BOTTOM WIDTH


10-YEAR EVENT
WATER ELEVATION AT TRANSECT 2
4.5
4
3.5
3
2.5
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing
6 by 12

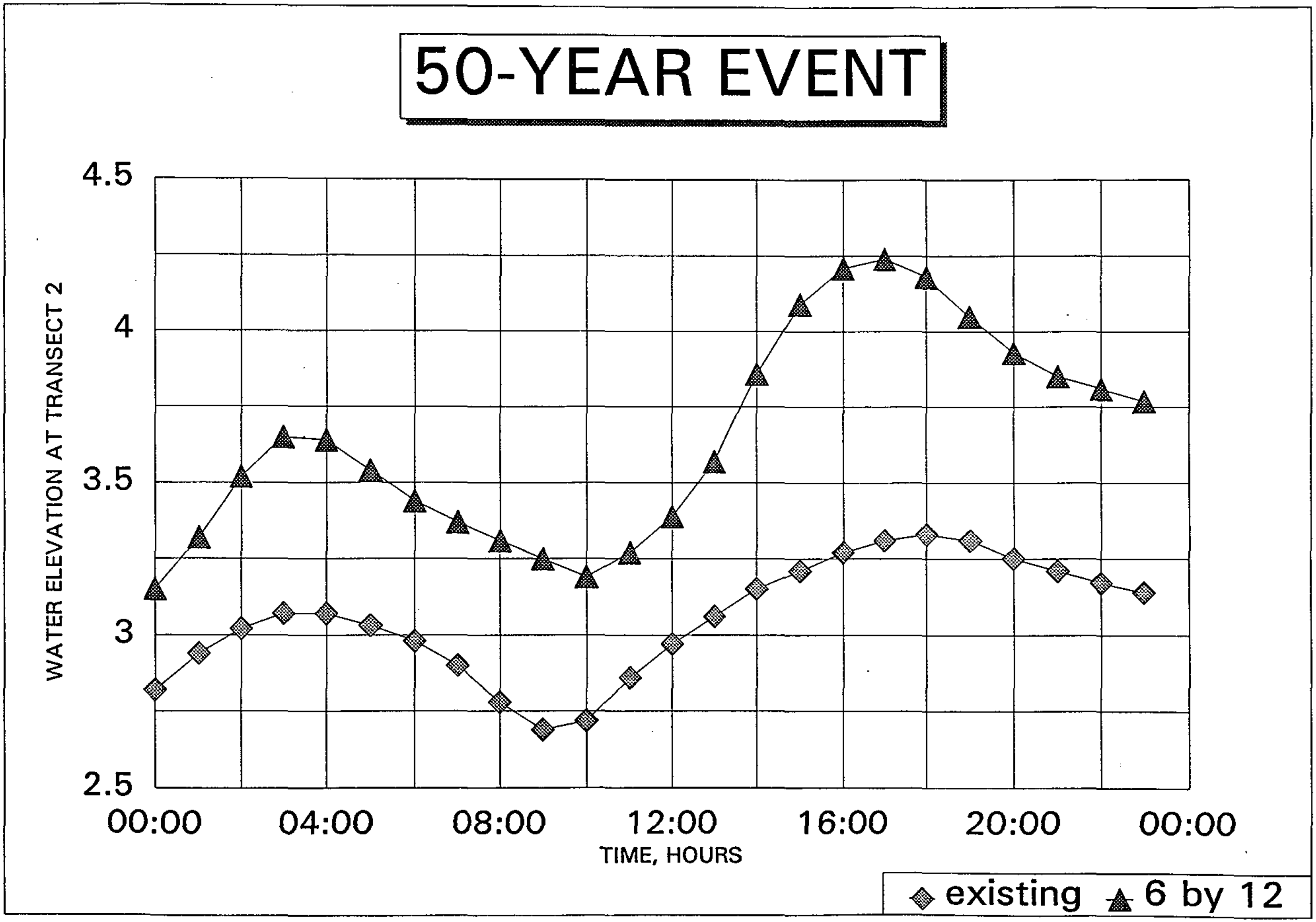
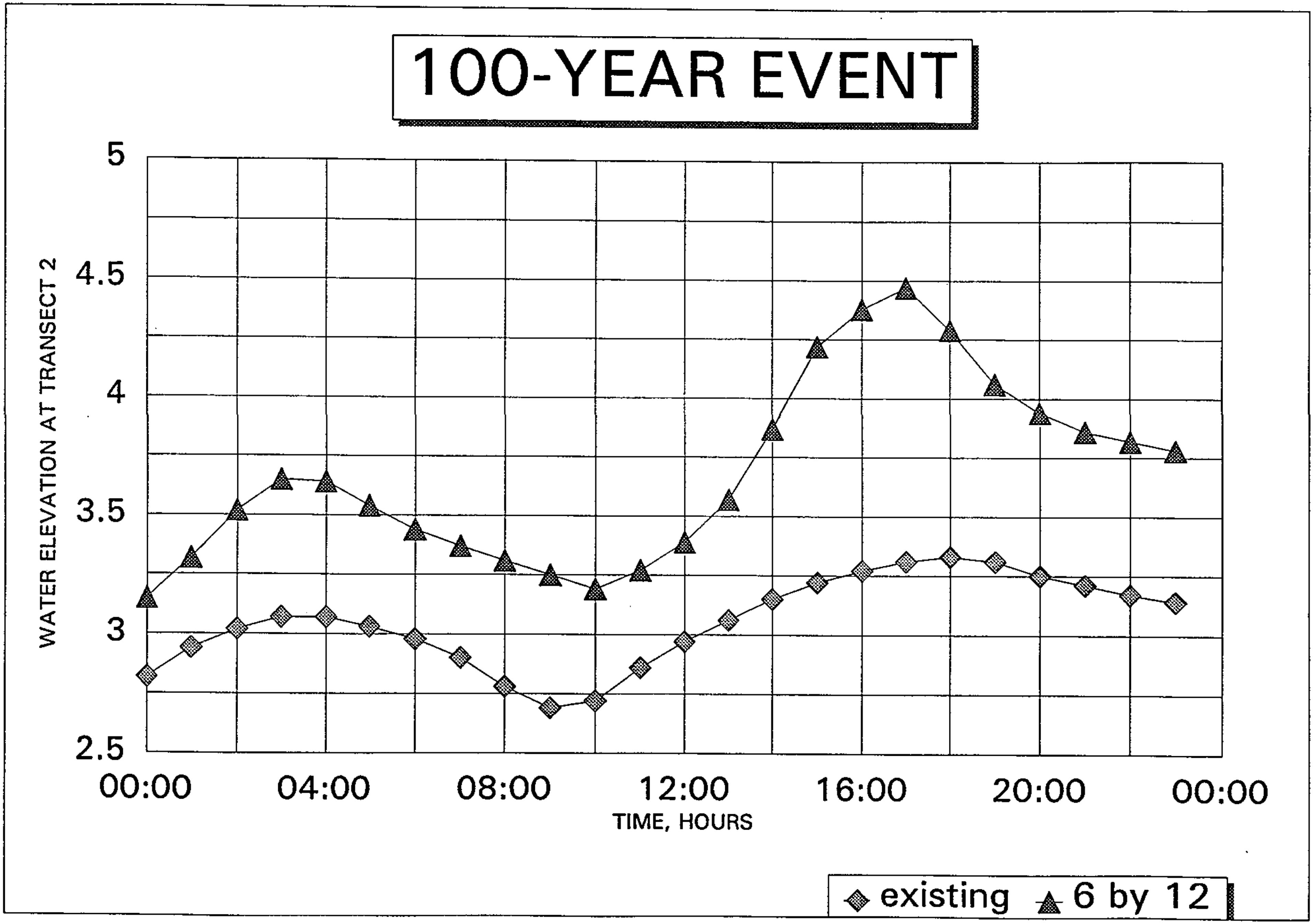
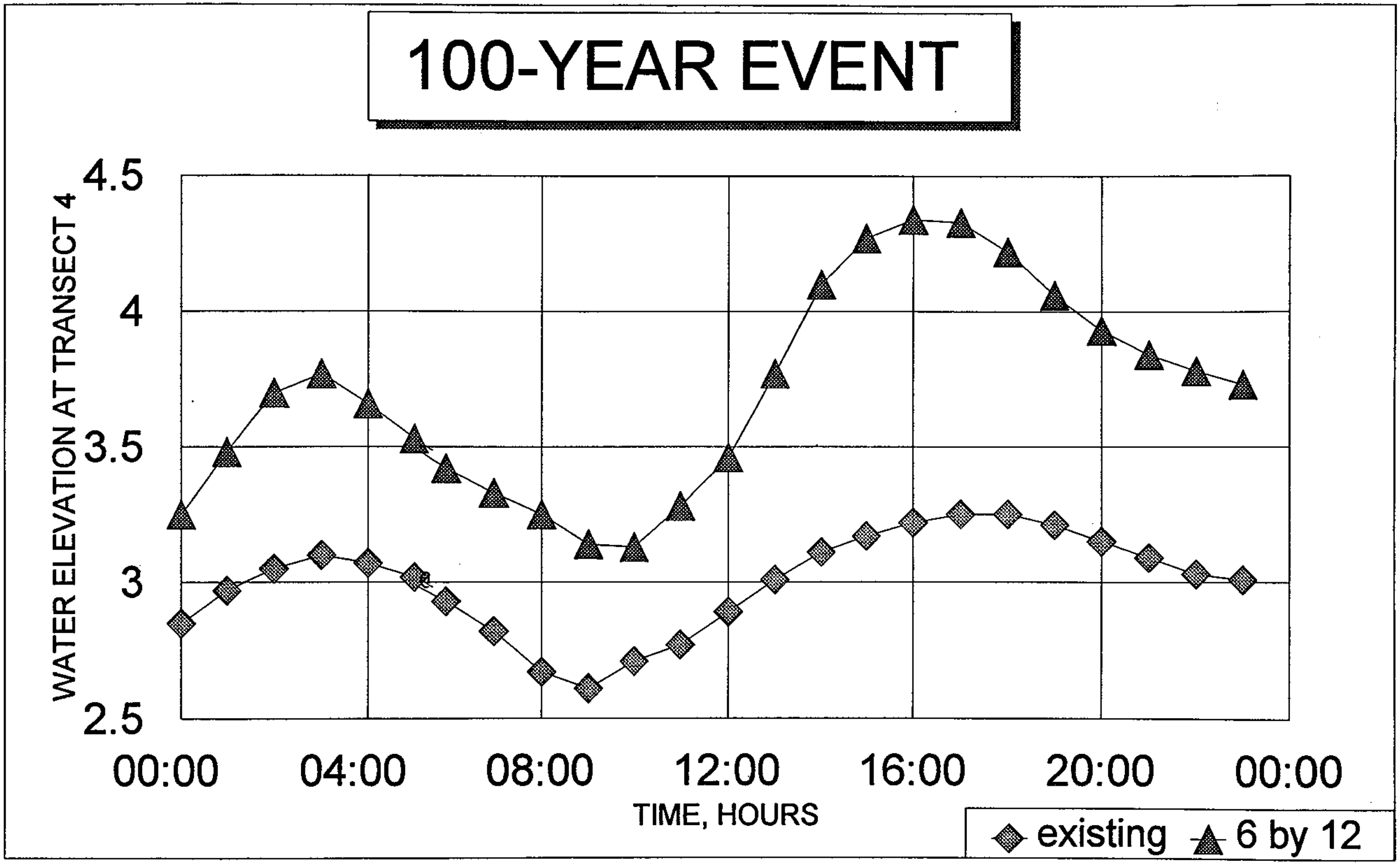

50-YEAR EVENT
4.5
4
3.5
3
2.5
WATER ELEVATION AT TRANSECT 2
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing
6 by 12

PLATE B-15


100-YEAR EVENT
5
4.5
4
3.5
3
2.5
WATER ELEVATION AT TRANSECT 2
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing
6 by 12



100-YEAR EVENT
WATER ELEVATION AT TRANSECT 4
4.5
4
3.5
3
2.5
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
existing
6 by 12

PLATE B-16a

APPENDIX C

INCREMENTAL ANALYSIS

MAIN REPORT
APPENDIX
INCREMENTAL ANALYSIS

INCREMENTAL ANALYSIS
FOR
SAGAMORE MARSH RESTORATION

SANDWICH, MASSACHUSETTS

U.S. Army Corps of Engineers
New England Division

INCREMENTAL ANALYSIS
TABLE OF CONTENTS

INTRODUCTION

The New England Division is investigating modification of Government-owned lands adjacent to the Cape Cod Canal to restore salt marsh and other estuarine habitats at the Sagamore Marsh (Figure 1). The purpose of this report is to evaluate and display the fish and wildlife habitat benefits and incremental costs of various alternatives for restoring the marsh. The incremental cost is the added cost for each additional unit of benefit. This information is used to help identify the best alternative for restoration.

Fish and wildlife resources may have both economic and ecological value. Corps of Engineers guidance describes fish and wildlife resources having substantial commercial and/or recreational value as National Economic Development (NED) resources. Those fish and wildlife resources having substantial non-monetary, ecological value are defined as Environmental Quality (EQ) resources. This incremental analysis will display the EQ outputs of alternative plans and compare the marginal cost of the various options.

This incremental cost analysis was prepared in accordance with Corps of Engineers Planning Policy (ER 1105-2-100). An incremental analysis is made up of the following steps:

a) Define environmental quality objectives
b) Determine units of measurement and appropriate models
c) Inventory and categorize fish and wildlife resources and determine significance
d) Conduct without project condition analysis
f) Formulate environmental plan increments
g) Conduct with-project analysis: Develop the supply of environmental quality outputs
h) Establish recommendations
i) Display Results

There are two major components of the preferred restoration alternatives explored in this analysis:

1) Culverts with flood control gates at the south end of the marsh.

2) Modification of the existing tidal channel at the south end of the marsh.

These components will be optimized through this incremental analysis.

ENVIRONMENTAL QUALITY OBJECTIVES

The Sagamore Marsh historically contained salt marsh and other estuarine habitats. This project is intended to restore salt marsh and other estuarine habitats by modifying the hydraulic connection to the Cape Cod Canal.

Project Mission

Restore salt marsh and other estuarine habitats within the Sagamore Marsh.

Project Goals

1) Restore tidal circulation to increase the area of estuarine aquatic habitat.

2) Maintain the quality of the existing in-channel estuarine habitats as much as practicable.

3) Increase the abundance of salt marsh vegetation (e.g., salt marsh cordgrass (Spartina alterniflora), salt meadow grass (Spartina patens), spike grass (Distichlis spicata), black grass (Juncus gerardi), etc.) and decrease the dominance of common reed (Phragmites australis).

4) Increase the habitat value for estuarine dependent fish and wildlife, while maintaining some cover for the existing wildlife community.

Project Objectives

1) Restore a tidal range that allows tides to flood the overbank areas without impacting homes, septic systems or groundwater drinking supplies.

Explore a range of alternatives, including one that maximizes tidal range within these limits, to increase the availability of estuarine aquatic habitat to estuarine organisms and maximize salt marsh primary productivity and production export.

2) Restore a frequency of tidal flooding that allows the establishment of salt marsh plants.

Maximize the area flooded between once daily and twice or more monthly to restore salt marsh. This will consist of areas of regularly flooded salt marsh cordgrass marsh and areas of irregularly flooded salt meadow (respectively).

Increase soil water salinity levels over large portions of the marsh to greater than 20 parts per thousand to discourage common reed and encourage salt marsh vegetation.

3) Provide suitable habitats for waterfowl, wading birds, sharp-tailed sparrows, and other salt marsh species, while maintaining cover for deer, foxes, and other large mammals presently using the site.

UNITS OF MEASUREMENT AND MODELS

The first step in an incremental analysis is to determine the resource units for measuring plan increments. Six types of habitat may be affected by this restoration project: 1) unvegetated intertidal habitats, 2) submerged aquatic vegetation, 3) low salt marsh, 4) high salt marsh, 5) common reed (*Phragmites australis*) marsh, and 6) freshwater shrub swamp. "Acres of salt marsh and estuarine habitat restored" is the most appropriate unit for this project because the diverse values provided by salt marsh and estuarine habitat are difficult to represent using other units such as productivity units or habitat units based on particular wildlife species.

Acres alone, however, do not allow a comparison of the quality differences associated with the culvert options. In particular, there are benefits associated with a larger tide range which will not be reflected by acres restored. More frequent and deeper flooding and more complete draining of the marsh with salt water can increase its productivity, the area periodically available for aquatic organisms, detrital (nutrient) export, and the transport of materials important to marsh functioning on and within the marsh. These factors can be considered in the selection of the recommended plan.

INVENTORY AND SIGNIFICANCE OF FISH AND WILDLIFE RESOURCES

Inventory. The area of existing cover types at the project site was estimated through interpretation of aerial photography and ground truthing. The Sagamore Marsh and contiguous wetlands consist of the following habitat types:

2.3 acres of tidal creeks;

1.3 acres of permanent ponds;

0.1 acre of pannes;

2.8 acres of short salt marsh cordgrass marsh;

6.5 acres of high marsh salt meadow (primarily salt meadow grass (S. patens) and spike grass (Distichlis spicata);

15.5 acres of stunted common reed marsh (Phragmites australis);

71.7 acres of tall common reed marsh;

9.0 acres of mixed common reed and shrubs;

0.6 acres of freshwater emergent wetland; and

63.3 acres of shrub swamp; and

15.4 acres of forested swamp.

The acres of various habitat types displayed above reflect the quantities of various vegetation types within the approximate limits of the 6-foot contour of the study area. This area was calculated using a topographic map with a two-foot contour interval and a scale of one inch equals one hundred feet. The area below elevation 6 ft NGVD is approximately 184 acres. The area of the Sagamore Marsh and contiguous wetlands measured from an aerial photography-based map totals 188.5 acres. The small difference in area between the two maps may result from differences in accuracy of the two products and/or the fact that contiguous forested/shrub swamp may extend above the 6-foot contour.

Significance. The incremental analysis procedure requires that fish and wildlife resources be assigned a relative significance based on national, regional, state and local importance and relative scarcity. The project site previously supported salt marsh and other estuarine habitats. Estuarine habitat is therefore the baseline against which the significance of existing resources is compared. Common reed marsh is presently the most abundant cover type, but a small amount of salt marsh is present and the main channel contains high value submerged aquatic vegetation (eelgrass, Zostera marina).

Common reed marsh has a relatively low value for fish and wildlife when compared to salt marsh. The National Research Council, Committee on the Restoration of Aquatic Ecosystems (NRC, 1992) included common reed in its discussion of aggressive, undesirable species. While common reed marsh exhibits many of the environmental quality values associated with wetlands, such as water quality maintenance and flood water detention, its value as fish and wildlife habitat is limited because of the low nutritional value of the plants and the fact that it often grows in dense stands to the exclusion of other plant types. This dense growth lowers plant diversity, an important index of habitat quality. Its most important wildlife value is the cover it provides.

A number of ecological and human use values are attributed to salt marshes. These include: wildlife, fish, and shellfish habitat; aquatic productivity enhancement; water quality maintenance; erosion control; and recreation and aesthetic values. All of these values are provided to some extent by the Sagamore Marsh and would be incrementally increased through the restoration of additional salt marsh.

The significance of salt marshes and estuarine intertidal habitat results from their high ecological value and the institutional value that has accordingly been placed upon them by the Federal and State governments. Estuarine habitat can exist only in the relatively narrow band along the coast affected by tides, contributing to its scarcity. The institutional value of salt marshes and mudflats is reflected in the fact that numerous Federal and state laws are aimed at their protection. Based on the level of protection they are afforded, society has placed a higher value on this habitat type than that of unregulated habitats.

The report, "Wetlands of the United States: Current Status and Recent Trends" prepared by the US Fish and Wildlife Service indicates that the United States had lost 54% of its original acreage of wetlands by the mid-1970's (Tiner, 1984). With respect to salt marsh, the report stated:

> "Efforts are now needed to restore degraded or modified wetlands to a more natural condition, so that they can once again serve as valuable fish and wildlife habitats."

The 1991 "Wetland Status and Trends Report to Congress" indicated that an additional 1.5% of the Nation's estuarine intertidal vegetated wetlands had been lost between mid-1970 and mid-1980 (Dahl and Johnson, 1991).

WITHOUT PROJECT CONDITION ANALYSIS

Under the Without Project Conditions or No Action Alternative, very little change in the composition of the marsh is expected. Successional change to shrub and forested wetland habitat would be very slow due to the tenacity of common reed and the continued potential for fires at the site. The predominance of shrubs was much greater prior to a 1981 fire on the marsh. Even with sea level rise, the amount of estuarine habitat on the site will be limited by the constriction of tidal inflow through the existing culverts.

ENVIRONMENTAL PLAN INCREMENTS

There are two components of the alternatives considered in this incremental analysis: 1) Culverts through the Cape Cod Canal and associated structures; and 2) Channels of various widths and lengths in the location of the existing riprap channel. The alternatives evaluated in this incremental analysis consist of combinations of these components. These alternatives are described in detail in the Feasibility Report.

Numerous hydraulic computer simulations were conducted using the UNET hydrodynamic model to estimate the effects of various combinations of culvert and channel sizes and inverts elevations. A team composed of the study manager, hydraulic engineer, environmental scientist, and economist met to review the results of preliminary runs of the hydrodynamic modeling to eliminate inefficient alternatives (alternatives with a higher cost for the same amount of benefits). Alternatives were compared based on the extent that they would increase tide levels (at a frequency of 2 tides per month) at one elevation transect location (Transect 2, Figure 2) and obvious changes in cost and environmental effects. A complete report on this process is provided in the Hydraulic Appendix. This evaluation led to the alternatives listed below.

<u>Alternative</u>

1) No Action
2) 6'X6' culvert
3) 6'X8' culvert
4) 6'X12' culvert
5) 6'X16' culvert
6) 10'X20' culvert with 30-foot channel to end of riprap
7) 2 6'X20' culverts with 40-foot channel to end of riprap
8) 2 10'X20' culverts with 40-foot channel to end of riprap

WITH PROJECT ANALYSIS

Marsh Flooding Evaluation.[1] The results of hydrodynamic modelling, surveyed elevation transects, topographic maps, and aerial photography were used to estimate the area of salt marsh restored with the various alternatives. The seven alternatives considered in this analysis are displayed in Column 1 of Table 1.

Other than the generalizations about the limits of salt marsh relative to tidal datums (e.g., mean high water, mean spring high water), specific criteria for determining the limits of marsh communities are not available. Therefore, information from the hydrodynamic model and existing plant communities was used to determine the most appropriate criteria in terms of flooding frequency to restore salt marsh at the Sagamore Marsh. This evaluation is described in Appendix IA-1. Based on this evaluation, a flooding frequency of eight times per month was determined to be sufficient to restore salt marsh.

The UNET hydrodynamic model was used to determine the tidal flooding heights for the range of culvert and channel size combinations at various locations in the marsh (in particular, the surveyed elevation transects and one interpolated transect) (Figure 2). The tide height attained at a frequency of 8 times per month was determined using the UNET model. This information is shown in Columns 2 and 3 of Table 1. Column 2 shows the model predictions and Column 3 shows the model results rounded to the nearest tenth.

The estimates of tidal height were converted to area flooded using the information from the surveyed elevation transects and topographic mapping. The section profiles from the elevation survey were printed at a horizontal scale of 1-inch equals 200-feet and a vertical scale of one-inch equals one-foot (Figures 3 through 8 are similar, but with a horizontal scale of 1-in = 150-ft and a vertical scale of 1-in = 4-ft). The length of each transect that would be flooded 8 times per month for each alternative was determined by drawing a line across the profile at the elevation of flooding shown in Column 3. The portion of the transect flooded at a given frequency is the length in feet below the estimated level of flooding. The results of this calculation are shown in Column 4.

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[1] There are limits to the accuracy of the information used to estimate benefits which may cause the actual area restored to differ from the predictions in this section. The information is probably most accurate in displaying differences among alternatives. The actual area restored with the project will most likely vary from predictions.

Table 1
Sagamore Marsh Restoration 8 times per month flooding criteria

ROW No.	ALTERNATIVE	COLUMN: 1	2 TIDE HEIGHT @ TRANSECT (ft NGVD)	3 ROUNDED (ft NGVD)	4 LENGTH FLOODED 8x/MONTH (ft)	5 % TRANSECT FLOODED 8x/MO. #4/TRANS LENGTH	6 AREA FLOODED 8x/MONTH (#5x T. AREA) (acres)	7 PREDICTED SM* -EXISTING SM AREA (acres)
1	TRANSECT 1							
2	EXISTING		2.96	3.0	195	0.21	6.35	0.43
3	6X6		3.38	3.4	330	0.36	10.74	4.82
4	6X8		3.45	3.5	370	0.41	12.04	6.12
5	6X12		3.56	3.6	410	0.45	13.35	7.43
6	6X16		3.63	3.6	410	0.45	13.35	7.43
7	10X20 w/30'		3.93	3.9	835	0.92	27.18	21.26
8	2-6X20 w/40'		4.10	4.1	850	0.93	27.67	21.75
9	2-10X20 w/40'		4.21	4.2	855	0.94	27.83	21.91
10	Area represented		29.62	acres				
11	Exist. salt marsh		5.92	acres				
12	Exist. shrt Pa&SM		8.18	acres				
13	Transect length		910	feet				
1	TRANSECT 2							
2	EXISTING		2.93	2.9	150	0.24	3.32	0.37
3	6X6		3.15	3.2	380	0.60	16.84	13.89
4	6X8		3.20	3.2	380	0.60	16.84	13.89
5	6X12		3.24	3.2	380	0.60	16.84	13.89
6	6X16		3.28	3.3	395	0.63	17.51	14.56
7	10X20 w/30'		3.45	3.5	475	0.75	21.05	18.10
8	2-6X20 w/40'		3.58	3.6	510	0.81	22.60	19.65
9	2-10X20 w/40'		3.67	3.7	520	0.83	23.05	20.10
10	Area represented		27.92	acres				
11	Exist. salt marsh		2.95	acres				
12	Exist. shrt Pa&SM		3.53	acres				
13	Transect length		630	feet				
1	TRANSECT 4A - East Actual (Phillips Road)							
2	EXISTING		2.98	3.0	50	0.05	3.01	0.31
3	6X6		3.09	3.1	50	0.05	3.01	0.31
4	6X8		3.12	3.1	50	0.05	3.01	0.31
5	6X12		3.15	3.2	50	0.05	3.01	0.31
6	6X16		3.18	3.2	50	0.05	3.01	0.31
7	10X20 w/30'		3.25	3.3	50	0.05	3.01	0.31
8	2-6X20 w/40'		3.29	3.3	50	0.05	3.01	0.31
9	2-10X20 w/40'		3.33	3.3	50	0.05	3.01	0.31
10	Area represented		58	acres				
11	Exist. salt marsh		2.7	acres				
12	Exist. shrt Pa&SM		2.7	acres				
13	Transect length		965	feet				
1	TRANSECT 4B - West Actual							
2	EXISTING		2.98	3.0	125	0.12	2.13	-0.51
3	6X6		3.09	3.1	170	0.17	2.90	2.68
4	6X8		3.12	3.1	170	0.17	2.90	2.68
5	6X12		3.15	3.2	650	0.65	11.07	10.85
6	6X16		3.18	3.2	650	0.65	11.07	10.85
7	10X20 w/30'		3.25	3.3	685	0.68	11.67	11.45
8	2-6X20 w/40'		3.29	3.3	685	0.68	11.67	11.45
9	2-10X20 w/40'		3.33	3.3	685	0.68	11.67	11.45
10	Area represented		17.12	acres				
11	Exist. Ch & sm		0.22	acres				
12	Exist. Ch, sPa&SM		2.64	acres				
13	Transect length		1005	feet				
1	TRANSECT 4C - South Predicted							
2	EXISTING		2.98	3.0	420	0.30	9.78	-2.05
3	6X6		3.09	3.1	520	0.38	12.10	10.90
4	6X8		3.12	3.1	520	0.38	12.10	10.90
5	6X12		3.15	3.2	580	0.42	13.50	12.30
6	6X16		3.18	3.2	580	0.42	13.50	12.30
7	10X20 w/30'		3.25	3.3	660	0.48	15.36	14.16
8	2-6X20 w/40'		3.29	3.3	660	0.48	15.36	14.16
9	2-10X20 w/40'		3.33	3.3	660	0.48	15.36	14.16
10	Area represented		32.12	acres				
11	Exist. salt marsh		1.2	acres				
12	Exist. shrt Pa&SM		11.83	acres				
13	Transect length		1380	feet				
1	TRANSECT 5							
2	EXISTING		3.03	3.0	10	0.01	0.09	-0.10
3	6X6		3.16	3.2	10	0.01	0.09	-0.10
4	6X8		3.18	3.2	10	0.01	0.09	-0.10
5	6X12		3.19	3.2	10	0.01	0.09	-0.10
6	6X16		3.21	3.2	10	0.01	0.09	-0.10
7	10X20 w/30'		3.28	3.3	10	0.01	0.09	-0.10
8	2-6X20 w/40'		3.32	3.3	10	0.01	0.09	-0.10
9	2-10X20 w/40'		3.35	3.4	15	0.01	0.13	-0.06
10	Area represented		10.93	acres				
11	Exist. channel		0.19	acres				
12	Exist. Ch, sPa&SM		0.19	acres				
13	Transect length		1220	feet				
1	TRANSECT 6							
2	EXISTING		2.99	3.0	295	0.46	3.91	3.72
3	6X6		3.09	3.1	330	0.52	4.37	4.18
4	6X8		3.12	3.1	330	0.52	4.37	4.18
5	6X12		3.16	3.2	430	0.67	5.70	5.51
6	6X16		3.18	3.2	430	0.67	5.70	5.51
7	10X20 w/30'		3.25	3.3	445	0.70	5.89	5.70
8	2-6X20 w/40'		3.30	3.3	445	0.70	5.89	5.70
9	2-10X20 w/40'		3.33	3.3	445	0.70	5.89	5.70
10	Area represented		8.45	acres				
11	Exist. channel		0.19	acres				
12	Exist. Ch, sPa&SM		0.19	acres				
13	Transect length		638	feet				

*SM=Salt marsh

The length flooded by a particular tide elevation was converted to area by assuming that each surveyed elevation transect represented elevations within an area of the marsh. The area represented by each transect was defined by comparing differences in physical and vegetation characteristics in the vicinity of each transect. Areas represented by specific transects are referred to as Transect Area 1, etc. The comparison of the area of existing salt marsh, tidal channel, and stunted common reed marsh (an indication of saline influence), revealed that areas originally assumed to be represented by Transects 2 and 4 should be modified.

Close inspection of the aerial photography and elevation transects showed that about half the area represented by Transect 2 is separated from tidal flooding by natural levees along the creek edge; therefore, the area flooded at Transect 2 (Column 6) under existing conditions was reduced by one-half. For similar reasons, Transect 4 was divided into two sections at the major creek, each representing a different area as shown in Figure 2. In addition, a third (interpolated) transect was established in this area to represent the a portion containing salt marsh and without creekbank levees. The main channel was included in Transect Area 4A.

The area in acres represented by each transect was measured by delineating the six-foot contour line on the topographic map and planimetering. This area (Acres represented) is shown on Row 10 of Column 1. The percentage of the transect flooded was calculated by dividing the length of the transect flooded at a given frequency shown in Column 4 by the total length of the transect under elevation 6-ft NGVD shown on Row 13. The estimated area flooded eight times per month is the percentage of the transect flooded (Column 5) multiplied by the acres represented (Row 10, Column 2) by each transect. The area flooded is shown in Column 6.

Some tidal flow occurs in the Sagamore Marsh under present conditions and the areas represented by Transects 1, 2, and 4 presently contain salt marsh. The area of existing salt marsh must be subtracted from the area to be restored to develop an accurate area of salt marsh restoration. The area of existing salt marsh, including tidal channels, (Row 11) was measured on 1993 aerial photography (Scale: 1"=600'; uncorrected for distortion) and subtracted from the area flooded for each of the flooding frequencies. The predicted area of salt marsh restored for each transect area is shown in Column 7.

Drainage. Periodic flooding and draining of salt marsh soils is important to plant growth and productivity (Nuttle, 1988). Inadequate drainage that results in waterlogged soil conditions limits the productivity of salt marsh cordgrass (Mendelsshon and Seneca, 1980) and may result in changes in high marsh plant community types that lower productivity and inhibit the ability of the marsh to accrete with sea level rise (Warren and Niering, 1993). Greater flushing may also contribute to stability of the marsh peat. At the Bride Brook salt marsh in Connecticut where the peat does not drain fully, there are signs that the marsh/open water ratio is decreasing. The periodic drainage associated with tidal fluctuations is most important for portions of the high marsh near the creekbanks. At distances greater than 12.5 meters from the creekbank, peat drainage may be dependent on evapotranspiration rather than lateral soil drainage (Nuttle, 1988). Based on information reported by Chapman (1960), Mitsch and Gosselink (1986) indicated that the high marsh has a minimum of ten days of continuous exposure per month. This period of exposure occurs between periods of intermittent tidal flooding.

Several factors complicate consideration of drainage at the Sagamore site. The existing main channels contain high quality eelgrass habitat. Impacts to this habitat should be avoided as much as practicable. Since eelgrass in general requires permanent flooding, complete drainage of the main channel at the Sagamore Marsh is not desirable. Therefore, the level of drainage of the marsh creeks must be sufficient to maintain salt marsh, but not so low that it would impact eelgrass. In addition, the ultimate level of tidal fluctuation at this site is limited by the fact the source of tidal flooding is not the same as the original source that developed when the marsh was formed. The Cape Cod Canal where tidal flow occurs under existing conditions has a mean tide range of 7.9 feet and a spring tide range of 9.0 feet. The mean tide range at Plymouth and Barnstable, which would be similar to the former tidal connection to the Sagamore Marsh, is 9.5 feet and the spring tide range is 11.0 feet (NOS, 1994). Therefore, it would be very difficult, if not impossible, to restore the former tide range to the Sagamore Marsh through the Cape Cod Canal. Conditions are further complicated by the fact that tidal flow now enters through the former upstream end of the marsh.

The sufficiency of drainage under existing conditions and with the various alternatives can be determined by comparing the existing and predicted low tide levels to marsh substrate elevations. The existing tide range in the channel was determined with the hydraulic model and tidal monitoring. The existing elevations of the marsh surface are available from the elevation survey, but the root zone of the marsh must be drained as well as the marsh surface. A core in the salt marsh at Transect Area 4 of the Sagamore

Marsh showed that the root zone extended to 0.7 feet (21 cm) below the marsh surface; therefore, with a slight margin of safety, the desirable level of drainage of the creeks is about 0.8 feet (25 cm) below the marsh surface.

Hydraulic model output from a run of the tide range at Transects 1, 2 and 4 with the 6x16 culvert (Figures 9 - 11) and each of the seven alternatives at Transect 2 (Figure 12) were used in the evaluation of drainage. The results of modelling with the 6x16 culvert represent median conditions and the results of modelling for Transect 2 show the relative tide range for each alternative.

When the new culverts and channels are installed, the level to which the marsh drains will decrease in the area represented by Transect 1 by about 0.1 foot during spring tides (Figures 3 and 9). The tide elevations will fall well below 0.7 feet (21-cm) below the edge of creekbanks. Drainage will be improved in this area.

At Transect 2, the lower limit of drainage will be at least one-tenth of a foot higher than under existing conditions during a spring tide. The lower low tide level will be below the level of the existing marsh surface (2.6-feet NGVD) and root zone (2.6-feet-0.8-feet=1.8 feet NGVD) (Figures 4 and 10). Drainage should be sufficient to drain the root zone at this transect during the lower of the diurnal spring tides.

At Transect 4, the level of permanent water will increase by about 0.2 foot from a minimum of about 2.9 feet NGVD during a spring tide to about 3.1 feet (Figures 6 and 11). To attain the existing level of drainage (i.e., 2-tenths of a foot less than predicted with the project), the channel would have to be deepened well into the interior of the marsh, impacting the eelgrass beds in the channel.

The increase in the low tide elevation will affect two parts of this area. Water is confined to the channel by creekbank levees in the area represented by Transect 4a. The increase in the level of permanent flooding would affect an additional 12 percent of Transect 4 if it were not confined to the channels by creekbank levees. Since the water will be confined to the creek, it is not expected to result in an increase in permanent flooding in the marsh interior.

The area represented by Transect 4c has no creekbank levees. This portion of the marsh was visited during a low tide to observe the level of low tide relative to the marsh surface to assess the effects of a 0.2 foot increase. The elevation of low water below the salt marsh surface ranged from 0.7-1.1 feet (22-33 cm) with a mean of 1 foot (29 cm) and standard deviation of 0.1 foot (4 cm). The elevation of low water below the common reed marsh surface ranged from 0.8-2.0 feet (24-60 cm) with a mean of 1.5 feet (45 cm) and standard deviation of 0.3 feet (10 cm). The marsh surface sloped upward from the creekbank. Based on these observations an increase of 0.2 feet in the level of the highest low tides would not adversely affect the marsh by permanently flooding the marsh surface or root zone.

Figure 12 shows that the level of low tide is lower with smaller culvert sizes. Selection of a smaller alternative will lower any uncertainty associated with drainage. As shown by Figure 11, the difference between alternatives is smaller in the interior of the marsh. The level of drainage is sufficient with all alternatives to avoid drowning of the marsh, but the larger alternatives could result in lower productivity over portions of the marsh.

Benefits Summary. The benefits of each of the alternatives are displayed below in Table 2. The "Total Area of Estuarine Tidal Regime Restored" shown in Column 1 includes the total area flooded eight times per month including existing salt marsh. Column 2 of Table 2, the "Total Area of Salt Marsh Restored", displays the units of benefits in the cost analysis.

Table 2. Acres of salt marsh restored for each of the culvert/channel alternatives.

	1 Total area of estuarine tidal regime restored	2 Total area of salt marsh restored
1) Existing	0	0
2) 6'X6'	50	37
3) 6'X8'	51	38
4) 6'x12'	64	50
5) 6'x16'	64	51
6) 10'x20' w/30'	84	71
7) 2-6'x20' w/40'	86	73
8) 2-10'x20' w/40'	87	74

All of these alternatives maintain permanent flooding in the existing channel that connects to the Canal; therefore, they will not result in the loss of the existing high value eelgrass from the main channel outside of the portion lined with stone protection.

Adaptive management. The conditions at this site dictate the need for close monitoring of the effects of the project and the need for fine tuning in implementation. In the future, additional salt marsh area may be restored by conducting additional site work. Table 2 shows the area of salt marsh restored without improvements to hydraulic conveyance on the marsh surface. Areas behind creekbank levees may not receive tidal salt water flow until creeks or existing lateral ditches, which have become cloged by common reed, are restored. Some of the lateral ditches may restore themselves over the long term as common reed or other vegetation regresses; however, channel improvements, which could be implemented in conjunction with mosquito control, would accelerate the restoration process.

Additional site improvements, such as mowing, may increase the area of saltmarsh restored beyond that reported here, but are not included in this analysis because they would not be implemented until three or more years after project construction.

DISPLAY OF BENEFITS AND COSTS

In this section, the costs of the alternative improvement plans are compared with the environmental benefits, within the framework of an incremental cost analysis, to display the most cost effective alternatives. An incremental cost analysis examines how the costs of additional units of environmental output increase as the level of environmental output increases. For this analysis, the environmental outputs are measured in acres, as calculated in the section above. This analysis is in accordance with IWR Report 95-R-1, <u>Evaluation of Environmental Investments Procedures Manual-Interim: Cost Effectiveness and Incremental Cost Analyses</u>, May 1995.

Increments under consideration involve six channel widths with six culvert sizes, either one or two culverts, and either stop logs or automatic tide gates. Channel widths are 6 feet, 8 feet, 12 feet, 16 feet, 30 feet and 40 feet. Culvert dimensions are 6' x 6', 6' x 8', 6' x 12', 6' x 16', 6' x 20' and 10' x 20'. Increments are numbered and shown in Table 3 in increasing magnitudes of habitat units, or acres. The terms increments. plans and alternatives are used interchangeably. There are 12 alternatives under consideration including the no project alternative.

The first costs shown in Table 3 represent are the sum of construction costs (includes escalation and contingency); planning, engineering and design (PED); and construction management. Annual outyear operation, maintenance and minor replacement costs are present worthed at an interest rate of 7 5/8 %. Corps guidance requires that this interest rate be used in evaluating Federal water resources improvement projects for Fiscal Year 96. There are no anticipated major replacements in outyears.

At this point, Alternatives 2, 4, 6, and 8 can be eliminated as being inefficient. An inefficient point means that the same amount or more habitat units could be obtained at a lower investment cost. Alternatives 2, 4, 6, and 8 have the same output as Alternatives 1, 3, 5, and 7, respectively, but at a higher cost. Thus, the detailed analysis will include the remaining 8 alternatives.

In comparing successive plans or increments, greater amounts of habitat units can only be obtained at a greater cost. Ideally, incremental costs divided by incremental habitat units should increase with increases in output or habitat units. This would facilitate answering the "is it worth it?" question as we compare successively larger plans. As can be seen in the last column of Table 4 the incremental cost curve increases through Alternative 3, decreases for Alternative 5, increases for Alternative 7, decreases for Alternative 9, increases for Alternative 10 and decreases for Alternative 11. The lumpy incremental cost curve shown in Table 4 is not useful for determining the recommended scale of plan. Lumpiness may be the result of not considering enough increments to provide the continuously increasing incremental cost curve. The lumpy data may be smoothed to give the incremental cost its desired shape. The smoothing process is described in Steps 7 through 9 found in the Procedures manual.

The first step in smoothing the incremental cost curve is to compute incremental habitat units (benefits) and incremental costs compared to the no project alternative. The plan with the lowest unit cost is identified and all plans (increments) producing less output are eliminated. In this case, Alternative 5 produces the lowest incremental cost. Alternatives 1 and 3 are thus eliminated as they have less output than Alternative 5 and higher incremental costs per unit than Alternative 5. This information is presented in Table 5. Alternative 5 consists of a 6' x 12' culvert with a 12' channel and stop logs.

The second step in the smoothing process involves the iterative procedure of recalculating the incremental cost per unit of each remaining plan relative to the last selected plan, and again selecting the plan with the lowest incremental cost per unit and deleting all plans that produce a lower output level. This iterative procedure is shown in Tables 6-A and 6-B. In Table 6-A incremental output and costs for Alternatives 7, 9, 10 and 11 are calculated with respect to Alternative 5 which was identified in Table 5 has having the lowest incremental cost when compared to the no project plan. The information for Alternative 5 is brought forward from Table 4. Inspection of the last column of Table 6-A indicates that Alternative 9 has the lowest incremental cost per unit. Alternative 7 is eliminated from further consideration as it involves less output at a higher unit cost and is thus inefficient. In Table 6-B Alternatives 10 and 11 are evaluated with respect to Alternative 9 which is the last selected plan, or alternative. Data for Alternatives 5 and 9 are carried forward from Table 6-A. In this table Alternative 11 is identified as having the lowest incremental cost and Alternative 10 is eliminated as its output is lower than Alternative 11 and its unit cost higher. As Alternative 11 is the last increment the smoothing process is complete. Table 7 summarizes the incremental outputs and costs of alternatives identified in Tables 5, 6-A and 6-B.

The incremental cost curve shown in Table 7 is the smoothed version of that shown in Table 4. Incremental costs per unit increase with output, or habitat units. Development of the incremental cost curve facilitates the selection of the best alternative. The question that is asked at each increment is: "Is the additional gain in environmental benefit worth the additional cost?".

RECOMMENDATIONS

The incremental analysis indicates that the lowest marginal cost per unit (acre) output occurs with Alternative 5 - 6' x 12' culvert with electric sluicegates and stoplogs.

The guidance on implementing incremental analysis states that:

> "Justification recommendations are arrived at by repeatedly and iteratively asking the question: is the next increment of output worth it by virtute of its explicitly defined significance and its relative scarcity, when compared to the cost of the increment?"

In other words, the plan with the lowest marginal cost is not necessarily the only plan that can be selected. Provided the cost of each additional output unit generated beyond the point of lowest incremental cost is "worth it", another plan may be selected. In this case, the recommended plan has the lowest marginal cost.

In addition to its lowest marginal cost, the recommended plan also allows sufficient drainage of the marsh peat during low tide which may be important to marsh productivity and has a lower potential to affect four-toed salamanders, a State-listed rare species. Larger alternatives would be more constrained by these factors. Therefore, the lowest marginal cost alternative is recommended.

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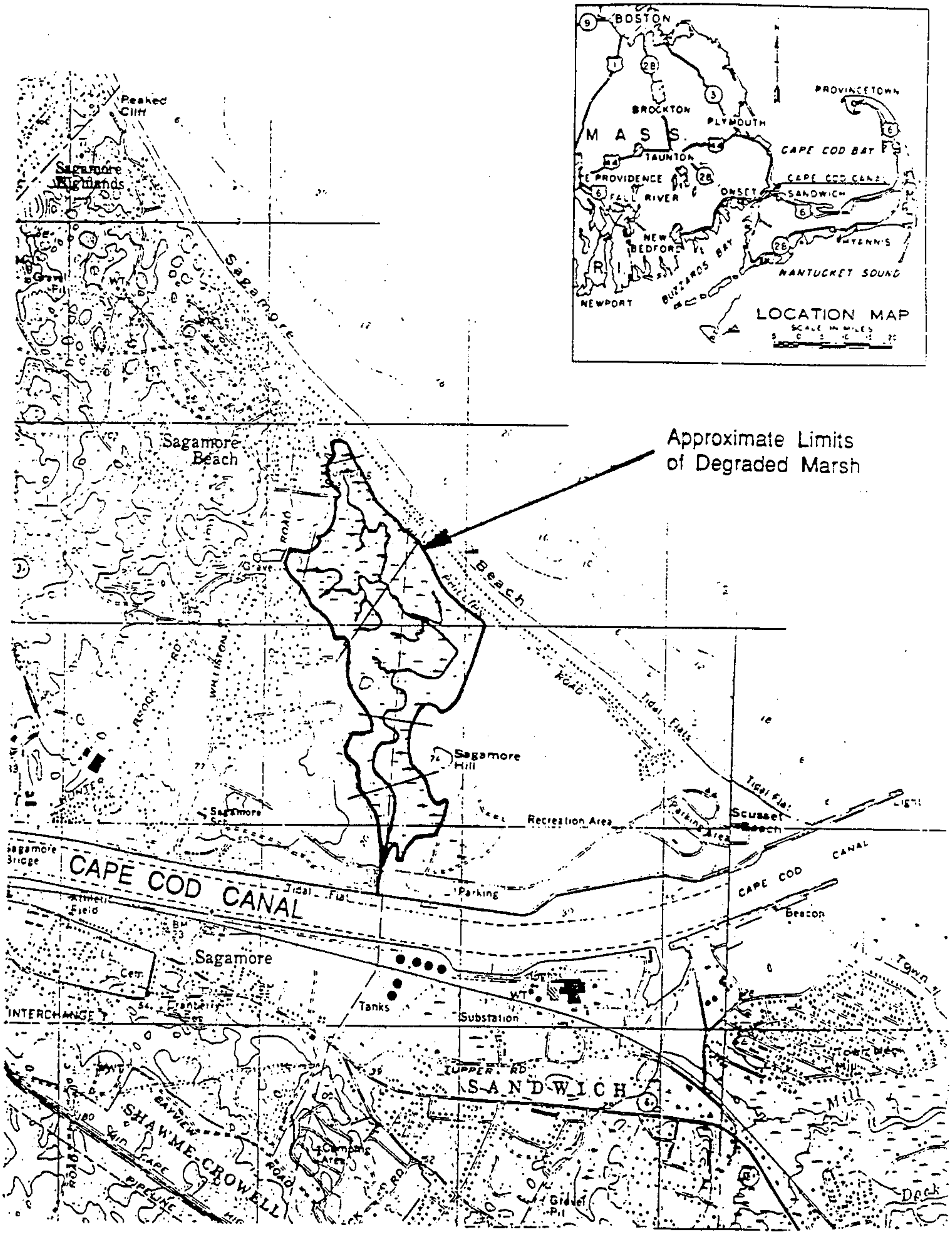
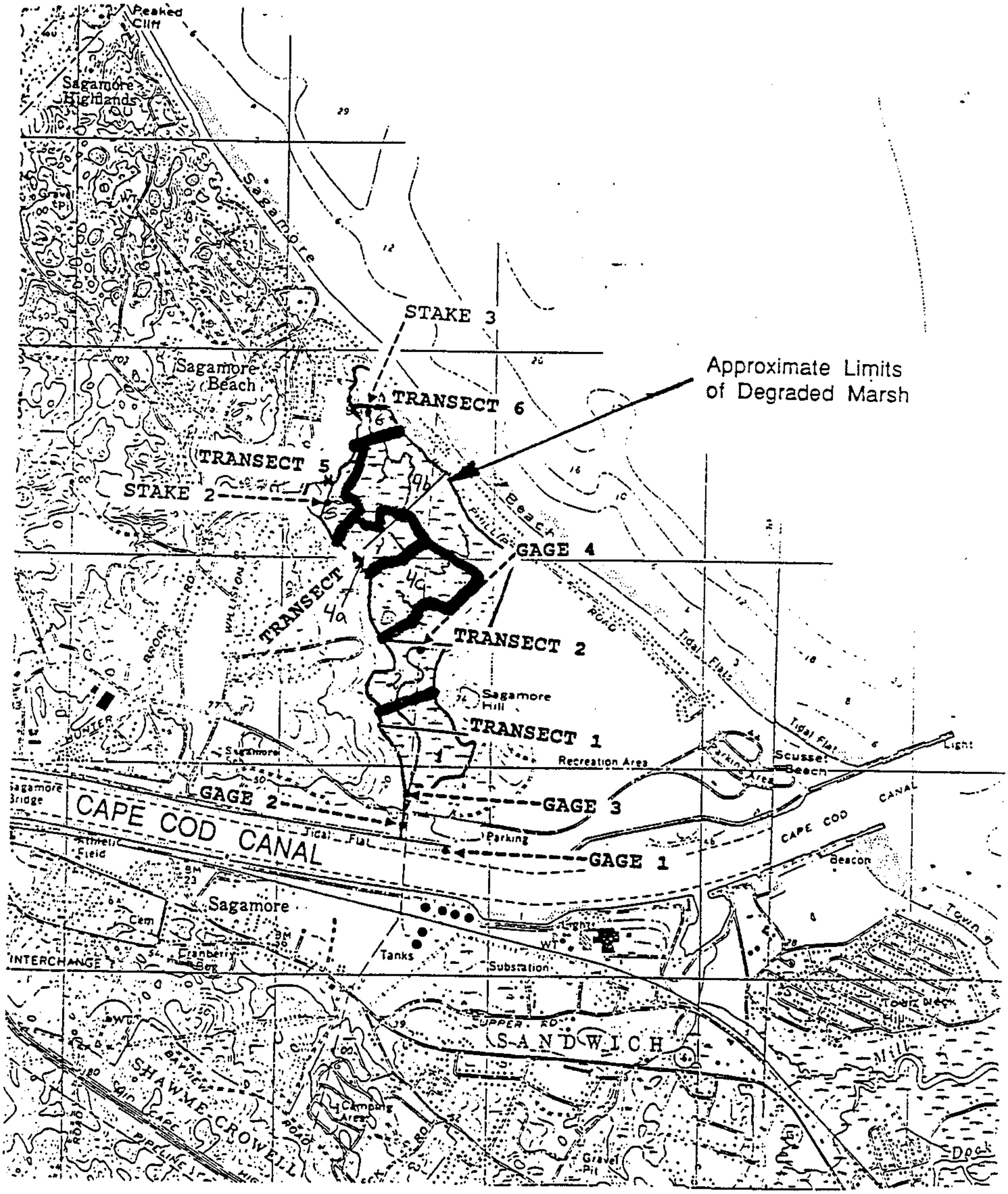


Figure 1

Sagamore Marsh Restoration

SAGAMORE MARSH RESTORATION

LOCATIONS OF TRANSECTS, TIDE GAGES, AND STAKES



Sagamore Marsh Restoration

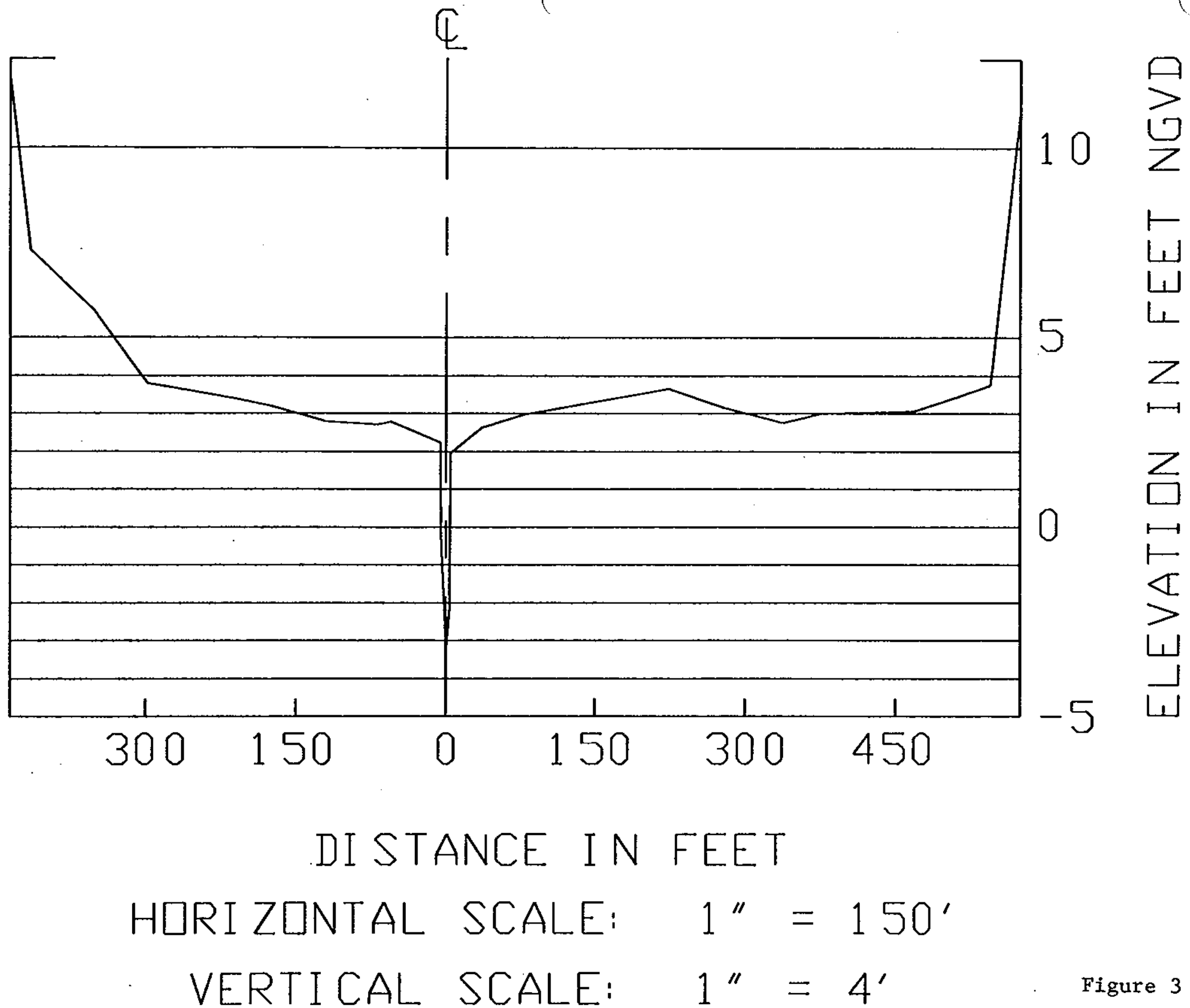
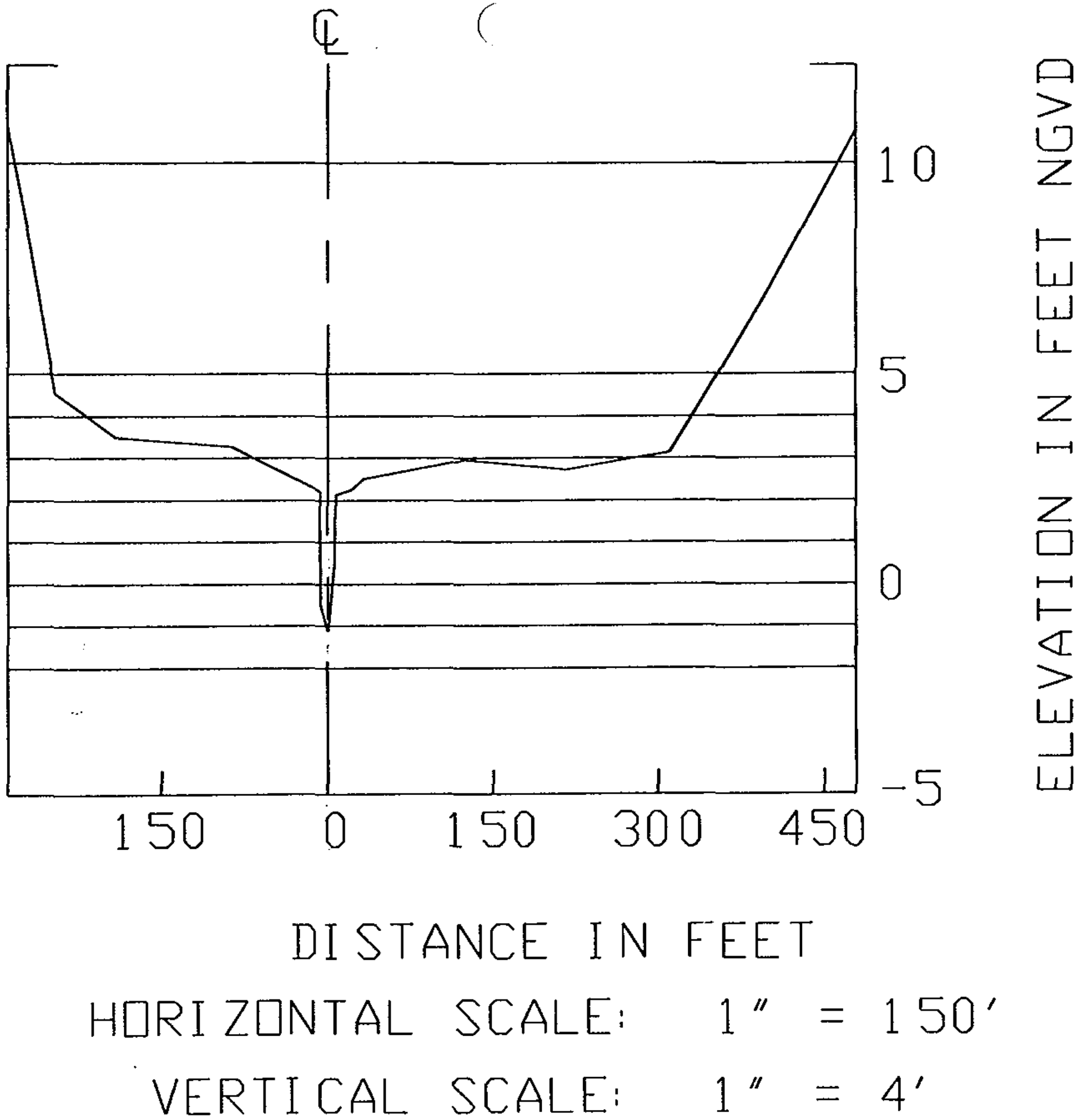


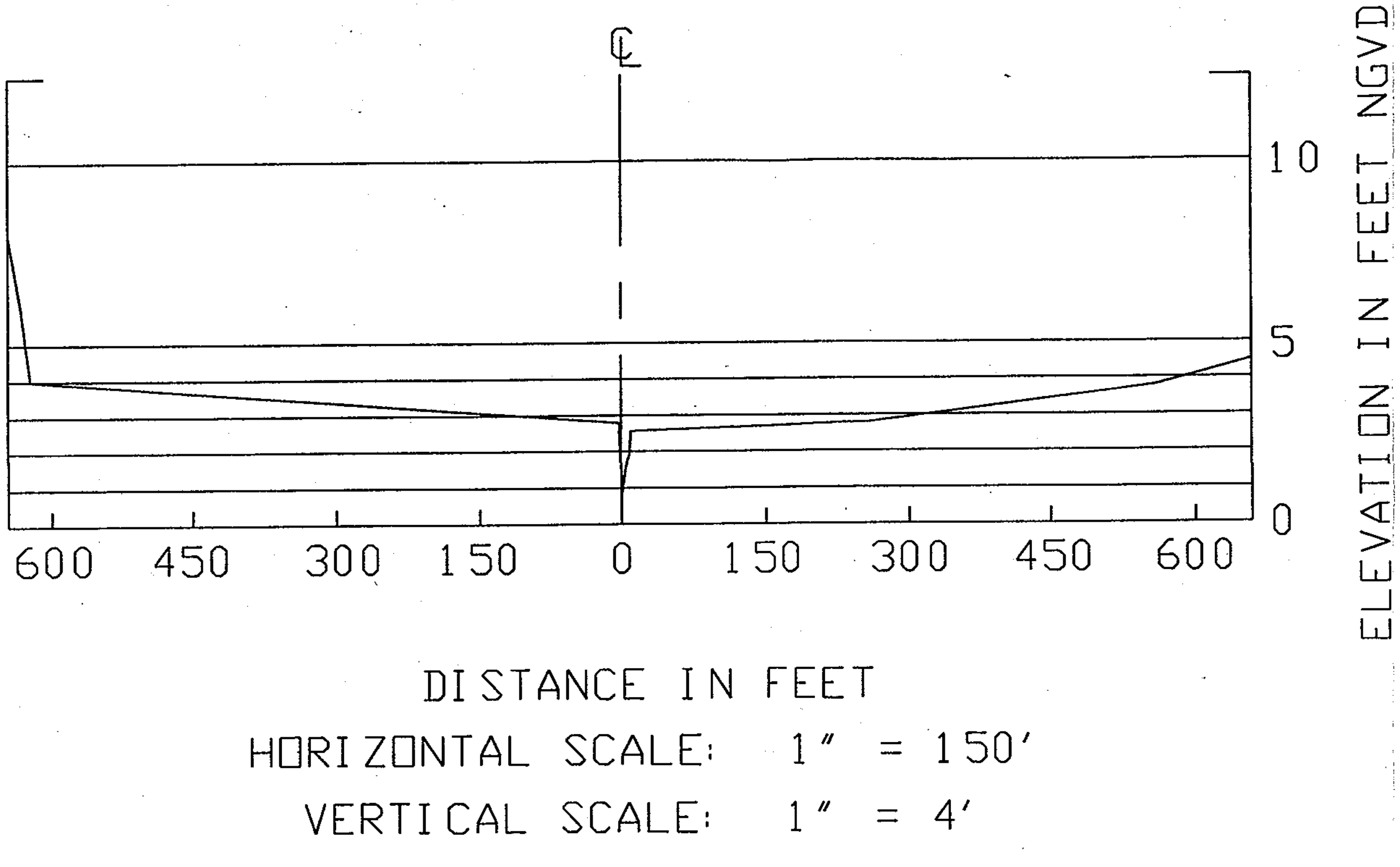
Figure 3

TRANSECT 1



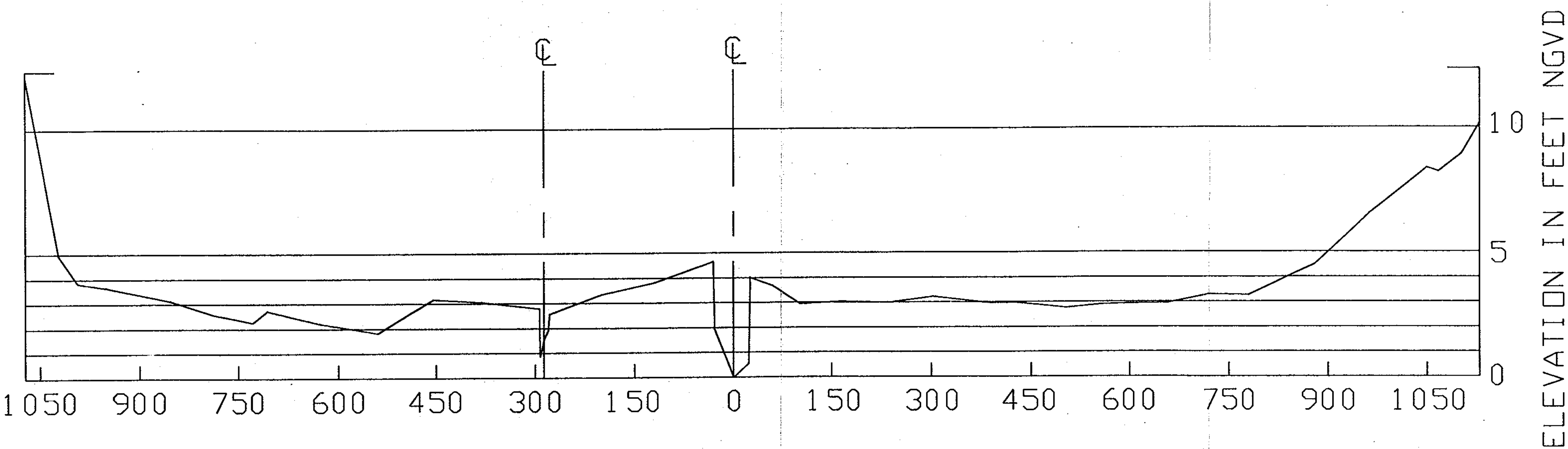
TRANSECT 2

Figure 4



TRANSECT 4C

Figure 5



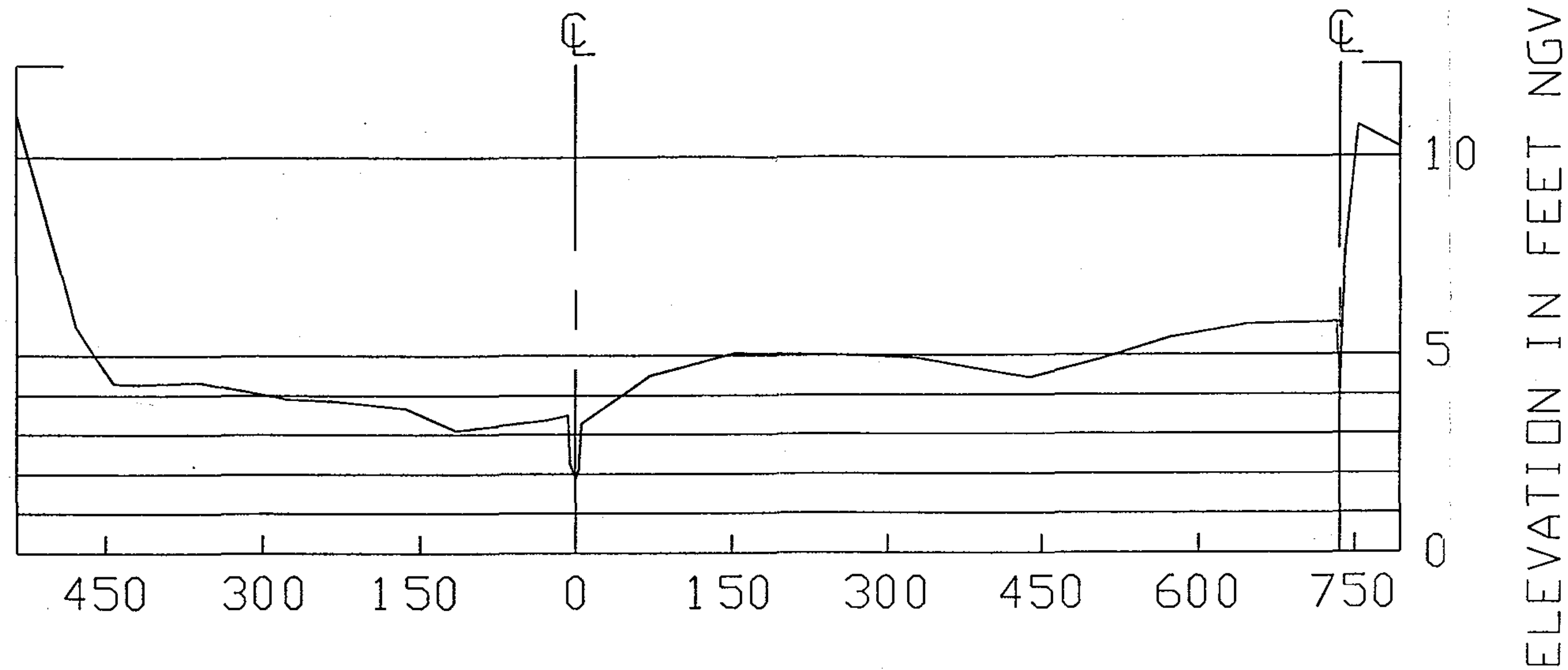
DISTANCE IN FEET

HORIZONTAL SCALE: 1" = 150'

VERTICAL SCALE: 1" = 4'

TRANSECT 4

Figure 6



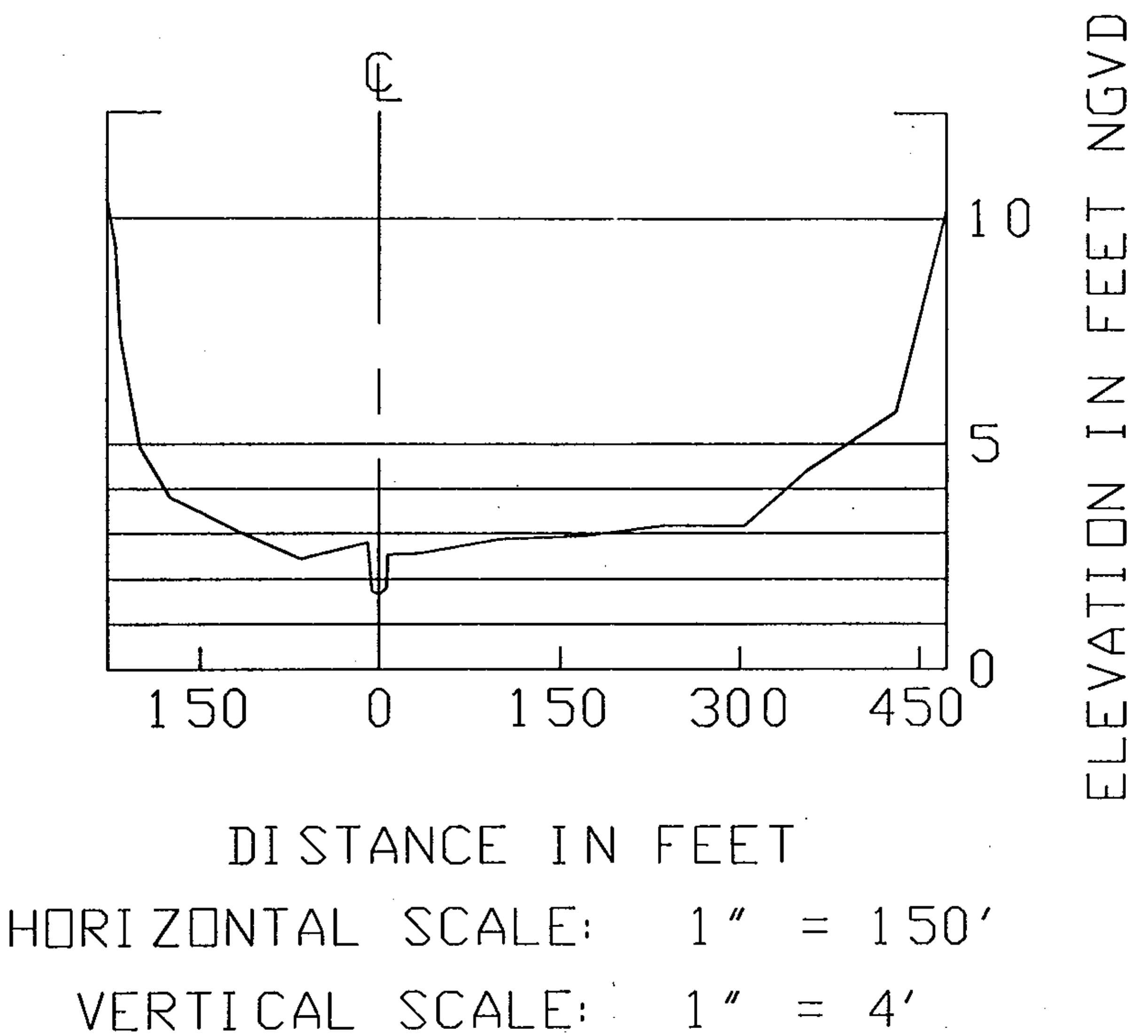
DISTANCE IN FEET

HORIZONTAL SCALE: 1" = 150'

VERTICAL SCALE: 1" = 4'

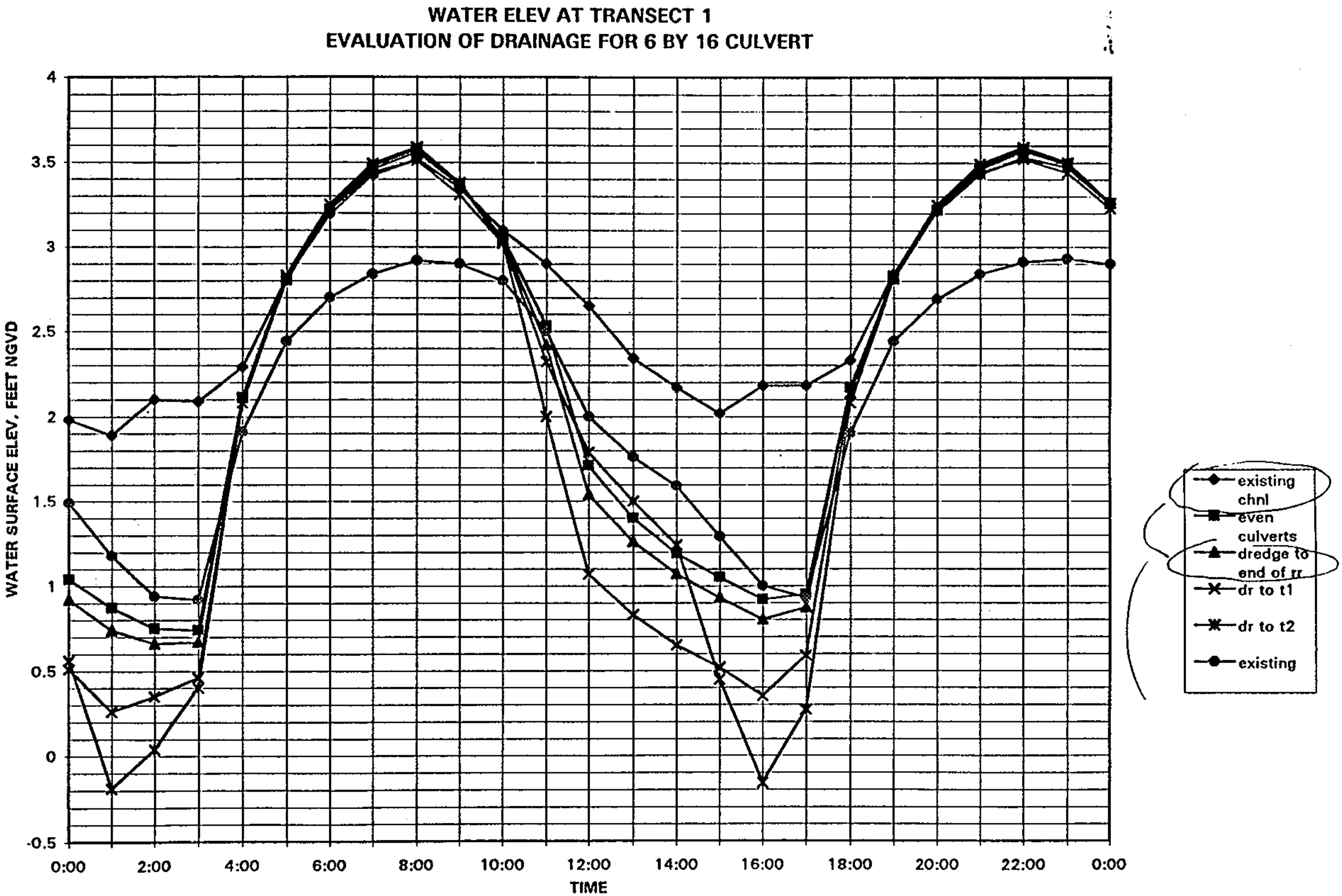
TRANSECT 5

Figure 7



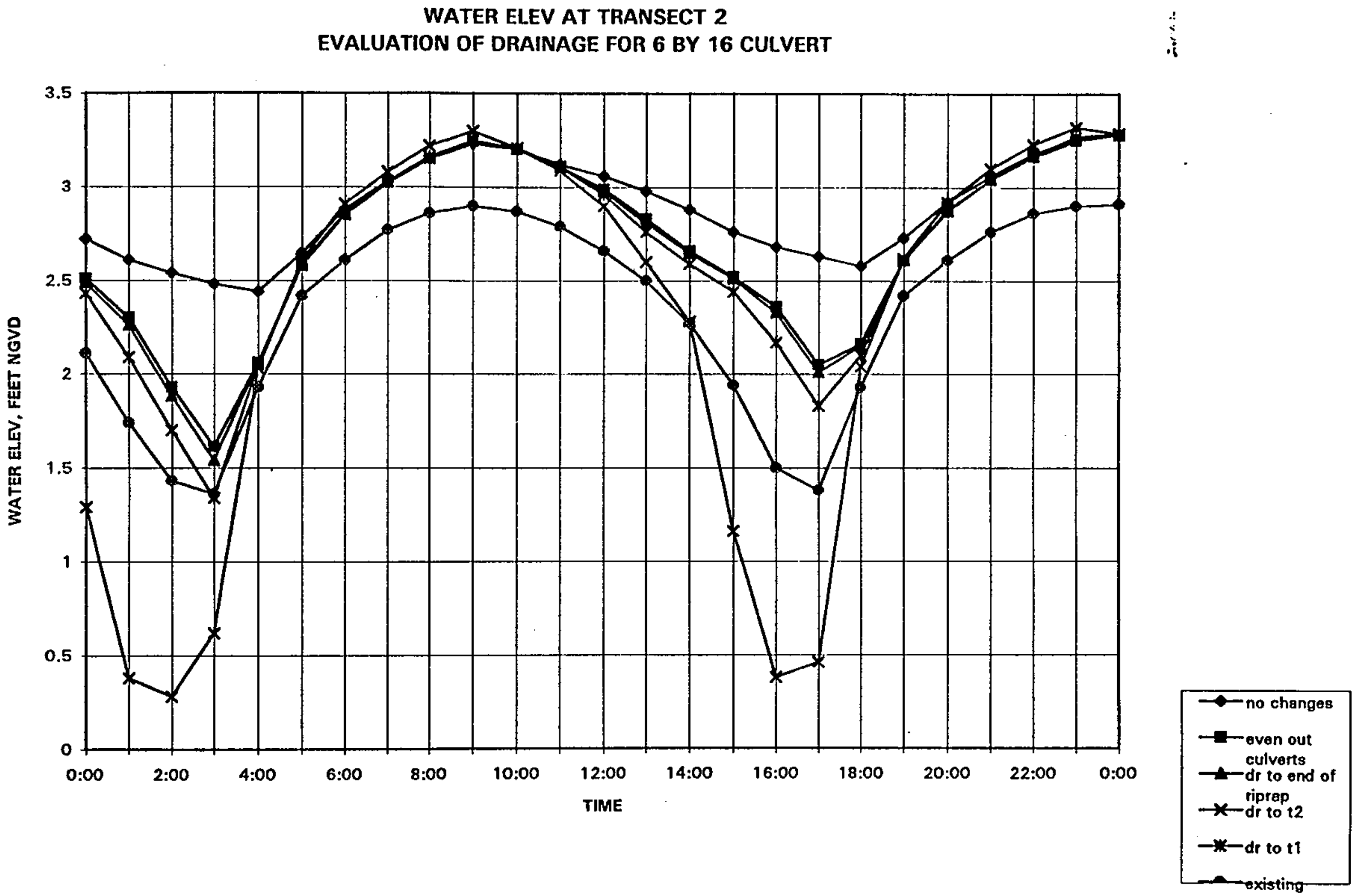
TRANSECT 6

Figure 8



WATER ELEV AT TRANSECT 1
EVALUATION OF DRAINAGE FOR 6 BY 16 CULVERT
WATER SURFACE ELEV, FEET NGVD
TIME
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
existing chnl
even culverts
dredge to end of rr
dr to t1
dr to t2
existing

Figure 9



WATER ELEV AT TRANSECT 2
EVALUATION OF DRAINAGE FOR 6 BY 16 CULVERT
WATER ELEV, FEET NGVD
3.5
3
2.5
2
1.5
1
0.5
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
TIME
no changes
even out culverts
dr to end of riprap
dr to t2
dr to t1
existing

Figure 10

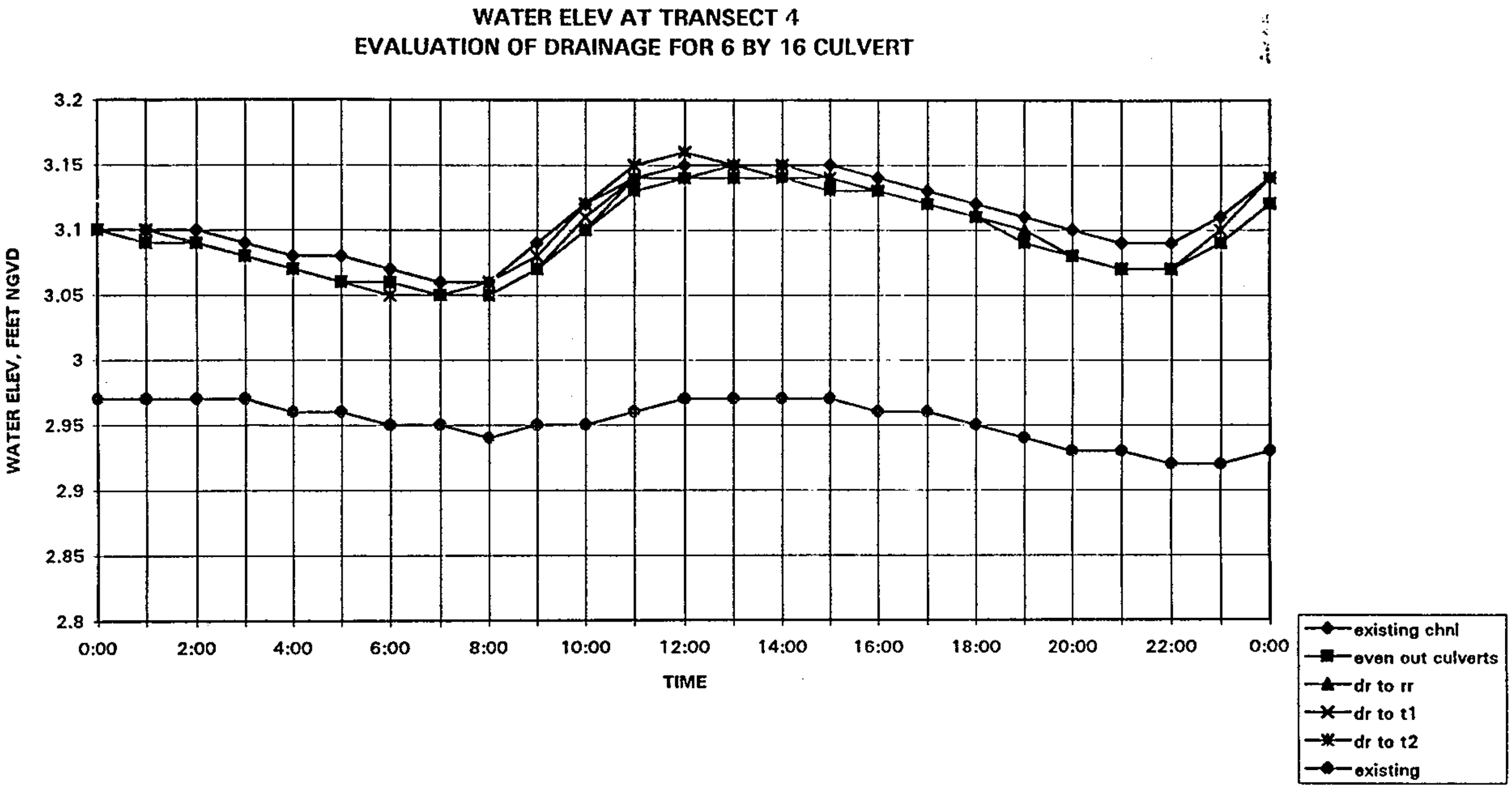

WATER ELEV AT TRANSECT 4
EVALUATION OF DRAINAGE FOR 6 BY 16 CULVERT
WATER ELEV, FEET NGVD
3.2
3.15
3.1
3.05
3
2.95
2.9
2.85
2.8
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
TIME
existing chnl
even out culverts
dr to rr
dr to t1
dr to t2
existing

Figure 11

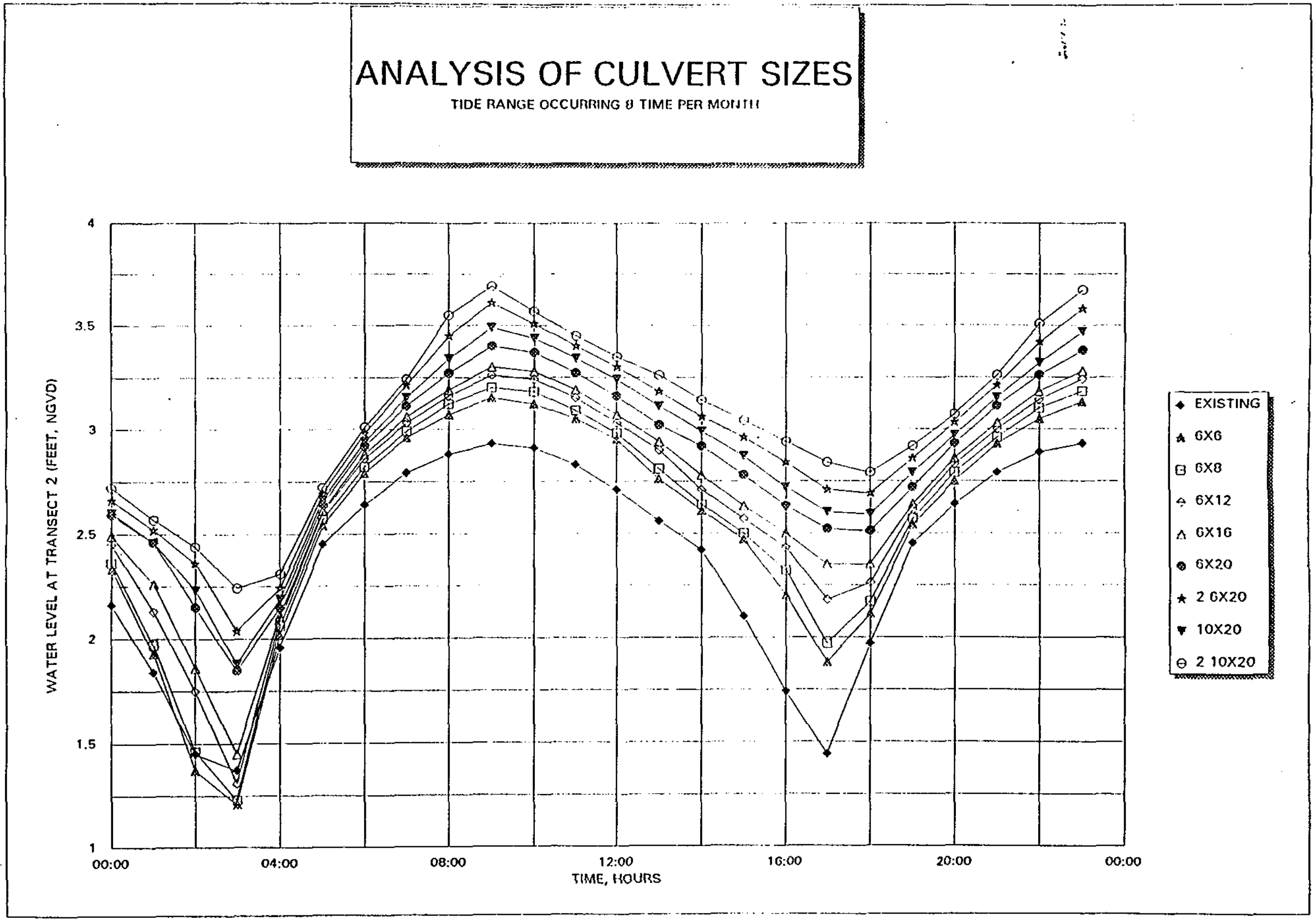

ANALYSIS OF CULVERT SIZES
TIDE RANGE OCCURRING 8 TIME PER MONTH
WATER LEVEL AT TRANSECT 2 (FEET, NGVD)
4
3.5
3
2.5
2
1.5
1
00:00
04:00
08:00
12:00
16:00
20:00
00:00
TIME, HOURS
EXISTING
6X6
6X8
6X12
6X16
6X20
2 6X20
10X20
2 10X20

Figure 12

TABLE 3

SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

Number	Increments	First Cost	Replace	O & M	Investment Cost	HU
0	No Project	0	0	0	$0	0
1	6 X 6+C6'+SL	$767,254	$0	$3,800	$815,800	37
2	6 X 6+C6'+AG	$943,650	0	$4,100	$996,100	37
3	6 X 8+C8'+SL	$897,870	$0	$4,300	$952,800	38
4	6 X 8+C8'+AG	$1,243,973	0	$4,700	$1,304,000	38
5	6 X12+C12'+SL	$991,850	$0	$4,700	$1,051,900	50
6	6 X12+C12'+AG	$1,566,971	0	$5,100	$1,632,200	50
7	6 X 16+C16'+SL	$1,239,447	$0	$5,100	$1,304,600	51
8	6 X 16+C16'+AG	$2,005,722	0	$5,600	$2,077,300	51
9	10 X 20+C30'+AG	$2,779,509	$0	$6,200	$2,858,800	71
10	2–6 X 20+C40'+AG	$4,439,660	$0	$8,400	$4,547,000	73
11	2–10X 20+C40'+AG	$5,241,640	0	$9,400	$5,361,800	74

Legend:

1. The first term under increments refers to culvert number and size.
The second term refers to channel dimension; the third term indicates channel width; the fourth term refers to automatic gates or stop logs

2. HU's– Total area of salt marsh restored

TABLE 4

SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

SUCCESSIVE PLANS

Number	Increments	Investment Cost	HU	Incremental Cost	Incremental HU	Incremental Cost/ Incremental HU
0	No Project	$0	0	n. a.	n. a.	n. a.
1	6 X 6+C6'+SL	$815,800	37	$815,800	37	$22,049
3	6 X 8+C8'+SL	$952,800	38	$137,000	1	$137,000
5	6 X12+C12'+SL	$1,051,900	50	$99,100	12	$8,258
7	6 X 16+C16'+SL	$1,304,600	51	$252,700	1	$252,700
9	10 X 20+C30'+AG	$2,858,800	71	$1,554,200	20	$77,710
10	2-6 X 20+C40'+AG	$4,547,000	73	$1,688,200	2	$844,100
11	2-10X 20+C40'+AG	$5,241,640	74	$694,640	1	$694,640

Legend:
1. H.U.=Habitat Units (acres of saltmarsh restored)
2. n.a. means not applicable
3. SL refers to stop logs; AG refers to automatic gates
4. C6' = development of 6' wide channel
5. C8' = development of 8' wide channel
6. C12' = development of 12' wide channel
7. C16' = development of 16' wide channel
8. C30' = development of 30' wide channel
9. C40' = development of 40' wide channel

TABLE 5

SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

COMPARED WITH NO ACTION PLAN

Number	Increments	Investment Cost	HU	Incremental Cost	Incremental HU	Incremental Cost/ Incremental HU
0	No Project	0	0	n.a.	n.a.	n.a.
1	6 X 6+C6'+SL	$815,800	37	$815,800	37	$22,049
3	6 X 8+C8'+SL	$952,800	38	$952,800	38	$25,074
5	6 X12+C12'+SL	$1,051,900	50	$1,051,900	50	$21,038
7	6 X 16+C16'+SL	$1,304,600	51	$1,304,600	51	$25,580
9	10 X 20+C30'+AG	$2,858,800	71	$2,858,800	71	$40,265
10	2−6 X 20+C40'+AG	$4,547,000	73	$4,547,000	73	$62,288
11	2−10X 20+C40'+AG	$5,241,640	74	$5,241,640	74	$70,833

Legend:
1. H.U.=Habitat Units (acres of saltmarsh restored)
2. n.a. means not applicable
3. SL refers to stop logs; AG refers to automatic gates
4. C6' = development of 6' wide channel
5. C8' = development of 8' wide channel
6. C12' = development of 12' wide channel
7. C16' = development of 16' wide channel
8. C30' = development of 30' wide channel
9. C40' = development of 40' wide channel

TABLE 6-A
SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

COMPARED WITH LAST SELECTED PLAN
(Alternative 5)

Number	Increments	Investment Cost	HU	Incremental Cost	Incremental HU	Incremental Cost/ Incremental HU
0	No Project	0	0	n.a.	n.a.	n.a.
1				[INEFFICIENT]		
3				[INEFFICIENT]		
5	6 X12+C12'+SL	$1,051,900	50	$1,051,900	50	$21,038
7	6 X 16+C16'+SL	$1,304,600	51	$252,700	1	$252,700
9	10 X 20+C30'+AG	$2,858,800	71	$1,806,900	21	$86,043
10	2-6 X 20+C40'+AG	$4,547,000	73	$3,495,100	23	$151,961
11	2-10X 20+C40'+AG	$5,241,640	74	$4,189,740	24	$174,573

Legend:
1. H.U.=Habitat Units (acres of saltmarsh restored)
2. n.a. means not applicable
3. SL refers to stop logs; AG refers to automatic gates
4. C12' = development of 12' wide channel
5. C16' = development of 16' wide channel
6. C30' = development of 30' wide channel
7. C40' = development of 40' wide channel

TABLE 6–B
SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

COMPARED WITH LAST SELECTED PLAN
(Alternative 9)

Number	Increments	Investment Cost	HU	Incremental Cost	Incremental HU	Incremental Cost/ Incremental HU
0	No Project	0	0	n.a.	n.a.	n.a.
1				[INEFFICIENT]		
3				[INEFFICIENT]		
5	6 X12+C12'+SL	$1,051,900	50	$1,051,900	50	$21,038
7				[INEFFICIENT]		
9	10 X 20+C30'+AG	$2,858,800	71	$1,806,900	21	$86,043
10	2–6 X 20+C40'+AG	$4,547,000	73	$1,688,200	2	$844,100
11	2–10X 20+C40'+AG	$5,241,640	74	$2,382,840	3	$794,280

Legend:
1. H.U.=Habitat Units (acres of saltmarsh restored)
2. n.a. means not applicable
3. SL refers to stop logs; AG refers to automatic gates
4. C12' = development of 12' wide channel
5. C30' = development of 30' wide channel
6. C40' = development of 40' wide channel

TABLE 7

SAGAMORE SALT MARSH
INCREMENTAL ANALYSIS

SUMMARY

Number Increments	Investment Cost	HU	Cost/ HU	Incremental Cost	Incremental HU	IncremCost/ Increm HU
0 No Project	0	0	n.a.	n.a.	n.a.	n.a.
5 6 X12+C12'+SL	$1,051,900	50	$21,038	$1,051,900	50	$21,038
9 10 X 20+C30'+AG	$2,858,800	71	$40,265	$1,806,900	21	$86,043
11 2-10X 20+C40'+AG	$5,241,640	74	$70,833	$2,382,840	3	$794,280

Legend:

1. H.U.=Habitat Units (acres of saltmarsh restored)
2. n.a. means not applicable
3. SL refers to stop logs; AG refers to automatic gates
4. C12' = development of 12' wide channel
5. C30' = development of 30' wide channel
6. C40' = development of 40' wide channel

APPENDIX IA-1
Salt Marsh Restoration Criteria

Introduction. Other than the generalizations about the limits of salt marsh relative to tidal datums (e.g., mean high water, mean spring high water), specific criteria for determining the limits of marsh communities are not available. Therefore, information from the hydrodynamic model and existing plant communities was used to determine the most appropriate criteria in terms of flooding frequency to restore salt marsh at the Sagamore Marsh.

Procedure. The results of hydrodynamic modelling, surveyed elevation transects, topographic maps, and aerial photography were used to estimate the area flooded at three frequencies to correlate to the area of existing salt marsh.

The tide height attained at frequencies of 2, 8, and 14 times per month was determined at five surveyed elevation transects and one interpolated transect using the UNET hydrodynamic model. Flooding frequencies of 2, 8, and 14 times per month were selected for the following reasons: The upper limit of salt marsh occurs at about mean spring high water up to the level of the highest astronomic tides (approximated for this evaluation at a more conservative frequency of 2 flooding tides per month). In the Cape Cod Canal near the Sagamore Marsh, mean spring high water occurs 14 times per month. This number of tides closely matches associations of flooding frequencies and vegetation types observed by Bertness and Ellison (1987) at a salt marsh in Barrington, RI. They found that the salt meadow grass (Spartina patens) zone was flooded just over half the days each month and the black grass (Juncus gerardi) zone was flooded by only the extreme spring tides of each month. The frequency of eight flooding tides per month was half-way between 2 and 14 times and is the number of flooding tides associated with salt marsh without common reed at the Galilee Salt Marsh in Rhode Island (D. Myshrall, University of Rhode Island, Department of Natural Resources Science, pers. com., May 1995). Tide heights attained at frequencies of 2, 8, and 14 times per month is shown in Columns C and D of Table 1. Column C shows the model predictions and Column D shows the model results rounded to the nearest tenth.

The estimates of tidal height were converted to area flooded using the information from the surveyed elevation transects and topographic mapping. The section profiles from the elevation survey were printed at a horizontal scale of 1-inch equals 200-feet and a vertical scale of one-inch equals one-foot (Figures E - 3 through 8 of the Incremental Analysis are similar with a revised scale for presentation). The length of each transect that would be flooded 2, 8, and 14 times per month for each alternative was determined by drawing a line across the profile at the elevation of flooding shown in Column D. The portion of the transect flooded at a given frequency is the length in feet below the estimated level of flooding shown in Column D of Table 1. The results of this calculation are shown in Column E.

The length flooded by a particular tide elevation was converted to area by assuming that each surveyed elevation transect represented elevations within an area of the marsh. The area represented by each transect was defined by comparing differences in physical and vegetation characteristics in the vicinity of each transect (Figure 2 of the Incremental Analysis). Areas represented by specific transects are referred to as Transect Area 1, etc.

The area in acres represented by each transect was measured by delineating the six-foot contour line on the topographic map and planimetering. This area (Acres) is shown in Row 6 of Column C. The percentage of the transect flooded was calculated by dividing the length of the transect flooded at a given frequency shown in Column E by the total length of the transect under elevation 6-ft NGVD shown on Row 5. The estimated area flooded at a particular frequency is the percentage of the transect flooded (Column F) multiplied by the acres represented (Row 6, Column C) by each transect. The area flooded is shown in Column G.

The comparison of the area of existing salt marsh, tidal channel, and stunted common reed marsh (an indication of saline influence), revealed that areas originally assumed to be represented by Transects 2 and 4 should be modified. Close inspection of the aerial photography and elevation transects showed that about half the area represented by Transect 2 is separated from tidal flooding by natural levees along the creek edge; therefore, the area flooded at Transect 2 (Column G, Rows 2-4) was reduced by one-half. For similar reasons, Transect 4 was divided into two sections at the major creek, each representing a different area as shown in Figure 2. In addition, a third (interpolated) transect was established in this area to represent the a portion containing salt marsh and without creekbank levees. The main channel was included in Transect Area 4A.

Some tidal flow occurs in the Sagamore Marsh under present conditions and the areas represented by Transects 1, 2, and 4 presently contain salt marsh. The area of existing salt marsh must be subtracted from the area to be restored to develop an accurate area of salt marsh restoration. This information has also been used to develop restoration criteria specific to this site. The area of existing salt marsh (Row 7) was measured on 1993 aerial photography (Scale: 1"=600'; uncorrected for distortion) and subtracted from the area flooded for each of the flooding frequencies. The predicted area of salt marsh restored for each transect area is shown in Column H.

The area of existing salt marsh and the predicted area of salt marsh based on flooding were compared to determine the most appropriate criterion (i.e., 2, 8, or 14 flooding tides per month), in terms of the number of flooding tides per month, to restore salt marsh. The basis for the comparison is:

> If a certain flooding frequency is an accurate predictor of restored salt marsh, then the area flooded at that frequency under existing conditions should be salt marsh.

This statement is particularly true at Transect Area 1 where tidal flooding most directly affects the marsh, creekbank levees are nearly absent, and dilution of salt water by freshwater is lowest. Therefore, Transect 1 was used to establish the flooding criteria for restoring salt marsh.

The comparison was made by subtracting the area of existing salt marsh (Row 7) from the area flooded a certain number of times per month (Rows 2-4, Column G) at Transects 1 and 2. Because of the potential for dilution of salt water by freshwater inflow in the upper reaches of the marsh (Transect Areas 4, 5, and 6), the area of stunted common reed (Row 8) was subtracted from the area flooded at a particular frequency, rather than the area of salt marsh. Stunting of common reed results from slightly lower salinity levels than required to maintain salt marsh. The results of these calculations were used as a check, but did not determine the flooding frequency criteria.

The closer the result (Rows 2-4, Column H) of the subtraction is to zero, the more accurate the criterion. Of the three tidal frequencies considered, 8 flooding tides per month was the closest to the area of existing salt marsh plus channel or the area of salt marsh, channel, and stunted common reed (smallest difference = 0.43 acres). The criterion of 8 flooding tides per month therefore is most appropriate to determine the area of salt marsh restored at this site.

Table 1. Sagamore Marsh - Salt Marsh Restoration Flooding Criteria

A	B	C Tide Height @Transect (ft NGVD)	D Rounded (ft NGVD)	E Length of Transect Flooded (ft)	F % Trans. Flooded cE/r5	G Area Flooded cFxr6 (acres)	H Predicted salt marsh-existing cG-r7 (acres)
1	Transect 1						
2	2x/month	3.05	3.1	225	0.25	7.32	1.40
3	8x/month	2.96	3.0	195	0.21	6.35	0.43
4	14x/month	2.92	2.9	150	0.16	4.88	-1.04
5	Trans. length	910 feet					
6	Area	29.62 acres					
7	Exist. ch & sm	5.92 acres					
8	Exist. shrt Pa	8.18 acres					
1	Transect 2						
2	2x/month	2.96	3.0	180	0.29	7.98	5.03
3	8x/month	2.93	2.9	150	0.24	3.32	0.37
4	14x/month	2.90	2.9	150	0.24	3.32	0.37
5	Trans. length	630 feet					
6	Area	27.92 acres					
7	Exist. ch & sm	2.95 acres					
8	Exist. shrt Pa	3.53 acres					
1	Transect 4a						
2	2x/month	2.99	3.0	50	0.05	3.01	0.31
3	8x/month	2.98	3.0	50	0.05	3.01	0.31
4	14x/month	2.97	3.0	50	0.05	3.01	0.31
5	Trans. length	965 feet					
6	Area	58.00 acres					
7	Exist. ch & sm	2.70 acres					
8	Exist. shrt Pa	2.70 acres					
1	Transect 4b						
2	2x/month	2.99	3.0	125	0.12	2.13	-0.51
3	8x/month	2.98	3.0	125	0.12	2.13	-0.51
4	14x/month	2.97	3.0	125	0.12	2.13	-0.51
5	Trans. length	1005 feet					
6	Area	17.12 acres					
7	Exist. ch & sm	0.22 acres					
8	Exist. shrt Pa	2.64 acres					
1	Transect 4c						
2	2x/month	2.99	3.0	430	0.33	10.71	9.51
3	8x/month	2.98	3.0	430	0.33	10.71	-1.12
4	14x/month	2.97	3.0	430	0.33	10.71	-1.12
5	Trans. length	1290 feet					
6	Area	32.12 acres					
7	Exist. ch & sm	1.20 acres					
8	Exist. shrt Pa	11.83 acres					

1 Transect 5						
2 2x/month	3.04	3.0	10	0.01	0.09	-0.10
3 8x/month	3.03	3.0	10	0.01	0.09	-0.10
4 14x/month	3.02	3.0	10	0.01	0.09	-0.10
5 Trans. length	1220 feet					
6 Area	10.93 acres					
7 Exist. ch & sm	0.19 acres					
8 Exist. shrt Pa	0.00 acres					
1 Transect 6						
2 2x/month	3.00	3.0	295	0.46	3.91	3.72
3 8x/month	2.99	3.0	295	0.46	3.91	3.72
4 14x/month	2.98	3.0	295	0.46	3.91	3.72
5 Trans. length	638 feet					
6 Area	8.45 acres					
7 Exist. ch & sm	0.19 acres					
8 Exist. shrt Pa	0.00 acres					

APPENDIX D

GEOTECHNICAL ANALYSIS

REPORT OF GEOTECHNICAL INVESTIGATION

FOR

SAGAMORE MARSH RESTORATION

AT

BOURNE AND SANDWICH, MASSACHUSETTS

OCTOBER 1995

REPORT OF GEOTECHNICAL INVESTIGATION
FOR
SAGAMORE MARSH RESTORATION
AT
BOURNE AND SANDWICH, MASSACHUSETTS

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1. INTRODUCTION

1.1 General. This report presents the results of geotechnical investigations performed for the proposed restoration of Sagamore Marsh in Bourne and Sandwich, MA.

1.2 Purpose and Scope. The purpose of the geotechnical investigation was to evaluate subsurface soil conditions at the site to assess the feasibility of replacing two existing 48-inch diameter culverts under the Canal Service Road and Scusset Beach Road with two 6-foot by 12-foot box culverts to increase tidal flooding.

The scope of the investigation included:

a. Field reconnaissance of the site.

b. Research and review of available subsurface data in the vicinity of the proposed culverts and existing channel.

c. Collection of subsurface soil samples by exploratory test borings at the Canal Service Road, Scusset Beach Road and along the existing channel and visual classification of the soils.

d. Laboratory testing of selected soil samples from borings on the Canal Service Road and Scusset Beach Road.

e. Geotechnical studies to establish foundation and material requirements.

f. Preparation of a geotechnical report to include Plan of Explorations, Engineering Log Profile, exploration field logs, subsurface foundation conditions, and conclusions and recommendations.

1.3 Project Description. Sagamore Marsh is a degraded salt-water marsh. The construction and maintenance of the Cape Cod Canal has greatly altered the geography, hydrology and ecology of the marsh by restricting tidal flooding. At present, the only tidal flooding enters the marsh from a 48 inch diameter culvert on the north side of the Cape Cod Canal. The existing 48 inch diameter culvert extends from the Cape Cod Canal revetment under the Canal Service Road for approximately 170 feet. Another existing 48 inch culvert extends under Scusset Beach Road for approximately 95 feet. An approximately 200 foot long riprap-lined channel connects the two culverts. An approximately 800 foot long riprap-lined channel extends from the culvert under Scusset Beach Road to the marsh. The inadequately sized culverts have led to the degradation of the majority of the marsh from a high value salt marsh to a lower value freshwater/brackish wetland overgrown with common reed (Phragmites australis) due to insufficient tidal flooding. A small portion of the marsh near the end of the existing channel receives adequate tidal flooding to allow the growth of salt marsh vegetation such as salt marsh cord grass (Spartina aterniflora).

The purpose of this study is to make recommendations on how to restore the Sagamore Marsh into a productive salt-water ecosystem. To increase tidal flooding in the marsh, the existing 48 inch diameter culverts will be replaced with 6 foot high by 12 foot wide box culverts under both the Canal Service Road and the Scusset Beach Road. The culverts under the Canal Service Road will be equipped with tide gates on the Canal side and sluice gates on the upstream end to control the amount of flood-waters allowed to enter the marsh. Access to the tide gates and the sluice gates for operation and maintenance will be designed during drafting of plans and specifications.

Construction of a temporary diversion trench or culvert will be necessary to allow the passage of water in and out of the marsh during the construction of the culverts. A temporary bypass road will be constructed to allow access to the State Park and Canal Service Road during construction.

2. SITE CONDITIONS.

2.1 Project Location. The Sagamore Marsh is located in a coastal area of southeastern Massachusetts. The marsh covers an area of approximately 300 acres which is bounded on the east by Cape Cod Bay and to the south by the Cape Cod Canal in the towns of Bourne and Sandwich, Massachusetts. The project location is shown on Figure 1 in Appendix A.

2.2 Topography and Geology. The Sagamore Marsh is located near the southeastern edge of a feature known as the Warham Pitted Plain. The land surface is characterized by a flat, gently sloping plain associated with glacial outwash plains and by Knob and Kettle topography associated with glacial moraines. The glacial outwash deposits consist mainly of stratified sand and gravel. The surficial outwash deposits grade laterally to finer graded glaciolacustrine deposits in the area around Sagamore Marsh. These deposits, consisting of interlayered gravel, sand, silt, and clay, are known as Cape Cod Lake deposits. Marine deposits overlie glacial deposits along the coast. These deposits consist of sand, silt, clay, and peat and are found in beach, tidal flat and salt-marsh environments.

2.3 Subsurface Explorations. Three exploratory borings, labeled FD-95-1, FD-95-2 and FD-95-3, are located as shown in Figure 2 in Appendix A. These exploratory borings were performed by Atlantic Testing Laboratories under contract with the Corps of Engineers. Two exploratory borings were located at the proposed culvert locations on the Canal Service Road and Scusset Beach Road. The third exploratory boring was located along the cart path beside the existing channel. The work was performed on 4-5 January 1995. The borings were located and monitored in the field by COE personnel. FD-95-1 and FD-95-3 were advanced to a depth of 42 feet and FD-95-2 was advanced to a depth of 37 feet. Hollow stem augers with 4 inch diameter were used to advance the borings, with wash boring techniques used as necessary to clean out and stabilize the hole. Standard Penetration Tests were performed to sample the soil in the holes at various depths using a 1-3/8 inch inner diameter split spoon and a 140 pound hammer with a 30 inch drop. Soil samples were visually classified on site in accordance with ASTM D 2488, "Description of Soils (Visual-Manual Procedure)".

Representative samples of the sand, sand with silt, silty clay and sandy clay were taken for soil testing. Laboratory tests consisted of grain size analyses and Atterberg limit tests. The laboratory results were used to verify and correct the visual classification of the soils for the exploratory boring logs found in Appendix B. The laboratory results can be found in Appendix B.

2.4 Subsurface Soil Conditions.

a. Canal Service Road. The subsurface soils beneath the Canal Service Road based on exploratory boring FD-95-1 consist primarily of loose to medium dense stratified sand (SP) and sand with silt (SP-SM). Top soil extends to a depth of approximately four inches followed by a layer of loose sand with gravel. A layer of dark brown organic silt (OL) overlaying dark brown organic silt (ML) was encountered nine feet from the surface, elevation 2 Ft- NGVD. The nine foot depth appears to be the original ground surface. The layer of silt overlays a layer of medium dense sand with silt followed by a gravel layer (GP). The gravel layer overlays a layer of loose to medium dense sand. The bottom of the boring was at a depth of 42 feet, elevation -31 ft-NGVD.

b. Scusset Beach Road. The subsurface soils beneath Scusset Beach Road based on exploratory boring FD-95-2 consist primarily of sands (SP) and sands with silt (SP-SM). Topsoil extends to a depth of approximately four inches followed by a layer of loose sand (SP), a layer of medium to loose sand with silt (SP-SM), and another layer of loose sand. At a depth of 16 feet, elevation -5 ft-NGVD, a layer of organic silt (OL) was encountered. Below the organic silt lies dense sand with silt followed by a layer of silty clay and a layer of sandy clay. The last layer encountered was a dense sand with silt. The bottom of the boring was at a depth of 37 feet, elevation -26.5 ft-NGVD.

c. Cart Path. The subsurface soils encountered along the cart path based on exploratory boring FD-95-3 consist primarily of sand and sand with silt. Topsoil extends to depth of four inches followed be a layer of loose sand overlaying loose to medium sand with silt. A layer of organic silt was encountered at a depth of nine feet, elevation -1.5 ft-NGVD. Below the organic silt lies a layer of dense sand with silt followed by a layer organic clay to a depth of 21 feet, elevation -14 ft-NGVD. Layers of medium to dense sands and sands with silt were encountered to a depth of 42 feet, elevation -35 ft-NGVD (bottom of boring).

The stratification of the subsurface soils is somewhat inconsistent. The layers of sand and sand with silt is probable fill overlaying a layer of native organic soil. The clay encountered in exploratory boring FD-95-2 does not appear in the exploratory boring FD-95-3 to the north or FD-95-1 to the south indicating an isolated clay pocket.

Groundwater was encountered at approximately elevation 2 ft-NGVD. The proposed culverts will be placed at invert elevation -2.7 ft-NGVD at the canal and -2.45 ft-NGVD at all other locations.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Design Criteria.

a. Based on the results of subsurface explorations, laboratory grain-size analysis, visual soil classifications, and experience with similar materials, the following soil characteristics are recommended for the design of the culverts and retaining walls for the enlargement of the culverts at Sagamore Marsh:

(1) Insitu:	
(a) In place unit weights:	γ_{sat} = 125 pcf
	γ_{moist} = 115 pcf
(b) Angle of internal friction	ϕ = 32°
(c) Coefficient of Active Earth Pres.	K_a = 0.31
(d) Coefficient of At Rest Earth Pres.	K_o = 0.47
(2) Compacted Random Fill:	
(a) In place unit weights:	γ_{sat} = 135 pcf
	γ_{moist} = 125 pcf
(b) Angle of internal friction	ϕ = 35°
(c) Coefficient of Active Earth Pres.	K_a = 0.27
(d) Coefficient of At Rest Earth Pres.	K_o = 0.43

b. A maximum bearing pressure of 3000 pounds per square foot is recommended for the design of the culvert and retaining walls.

c. Subsurface explorations performed for this project show that driving sheet piling around the work area should not present a problem. Prior to driving steel sheet piling all surface cobbles and boulders must be stripped from the proposed line of sheeting.

3.2 Erosion Protection. During channel widening, the existing stone riprap should be removed from the channel, stockpiled and reused. Existing riprap will be passed over a grizzly to remove fines. At a minimum, the riprap should extend from the invert of the channel to approximately 1 foot above mean high water (see Figure 6 in Appendix A). The channel between the culverts should be riprapped. The channel between the upstream culvert and the marsh should be riprapped to the limit of channel widening. Riprap should be extended on the embankment around the culverts. It may be necessary to construct a concrete apron with a cutoff wall under the gate structures and ends of culverts to ensure that scouring does not occur.

3.3 Settlement. A layer of peat and organic material was encountered during the exploratory boring program approximately at elevation 2 to -5 ft-NGVD. Where encountered this peat layer should be removed and be replaced with compacted gravel to a minimum depth of 3 feet below the bottom of the culverts to minimize any settlement.

3.4 Pavement. Bituminous concrete pavement should be constructed in accordance with Section 460 of the Commonwealth of Massachusetts, Department of Public Works, Standard Specifications for Highways and Bridges, 1988, as amended. This publication will be subsequently referred to as the State Specifications. Bituminous concrete should be placed on a gravel base course compacted to 95 percent of its maximum dry unit weight as determined by ASTM D 1557.

The recommended pavement section is as follows:

a. Canal Access Road

LAYER	THICKNESS
Bituminous Concrete Surface Course	2 inches
Bituminous Concrete Binder Course	2 inches
Gravel Base Course	12 inches

b. Scusset Beach Road

LAYER	THICKNESS
Bituminous Concrete Surface Course	1-1/2 inches
Bituminous Concrete Binder Course	1-1/2 inches
Gravel Base Course	12 inches

3.5 Material Recommendations.

a. Gravel Fill. Gravel fill to be placed and compacted under retaining walls and culverts should conform to Section 405, "Gravel Base Course", of the State Specifications and Section M1.03.0 Type a.

Sieve Designation (U.S. Standard)	Percent Passing By Weight
6 inch	100
1/2 inch	50 - 85
No. 4	40 - 75
No. 50	8 - 28
No. 200	0 - 10

b. Gravel Base Course. Gravel fill to be placed and compacted under retaining walls and culverts should conform to Section 405, "Gravel Base Course", of the State Specifications and Section M1.03.0 Type b.

Sieve Designation (U.S. Standard)	Percent Passing By Weight
3 inch	100
1/2 inch	50 - 85
No. 4	40 - 75
No. 50	8 - 28
No. 200	0 - 10

c. Random Fill. Random fill material to be used for backfill should be free draining, granular material obtained from the required excavations for the project. The material should be free of silt, clay, topsoil, roots, debris, and shall not contain stones larger than two-thirds of the thickness of the layer being placed.

d. Bituminous Concrete. Bituminous concrete materials should meet the requirements of Section 460 of the State Specifications.

3.6 Design and Construction Considerations.

a. Channel Design. Incremental Analysis determined that channel widening is necessary to achieve increased flooding in the marsh area. The channels will be widened to 12 ft across the bottom with a side slope of 2 horizontal to 1 vertical. The existing riprap will be reused on the widened channel bottom and side slopes to a minimum height of 1 foot above mean high water (see figure 6 in Appendix A). The existing riprap appears to be adequately sized for reuse based on the tide ranges, depth of channel, and expected velocities through the channel.

Suitable excavated materials will be used for random fill as needed. Dredged materials, organic silts and peat will be disposed of off site. Information on disposal of dredged and excavated materials will be addressed in the plans and specifications.

Construction equipment will be able to access the salt marsh from Scusset Beach Road. Areas will need to be cleared as necessary to access the interior sections of the existing channel. Designated sections of the area will need to be cleared for use as a staging area during construction.

b. Canal Service Road and Scusset Beach Road Culverts. Based on the subsurface explorations performed at the proposed culvert locations, it appears the proposed culvert construction would encounter saturated, loose to medium dense sand and sand with silt overlaying a layer of organic materials. At Scusset Beach Road, the sand layer overlays a clay layer. Unsuitable materials such as clay and organic silts and peat should be removed to a minimum depth of 3 feet below the invert of the culvert to minimize settlement.

Groundwater was observed at approximately elevation 2 ft-NGVD in the borings. The excavation for the culvert will have to be dewatered whether precast or cast-in-place culverts are installed. A temporary earth support system will need to be utilized to facilitate construction. The earth support system will be installed around the proposed culvert locations with the interior dewatered by pumps.

To permit water to flow at the volume currently found in the drainage channel a temporary 48" culvert should be provided and maintained throughout construction of the permanent culverts. A temporary earth support system should be utilized during the installation of the temporary diversion culverts at the Canal Service Road and Scusset Beach Road.

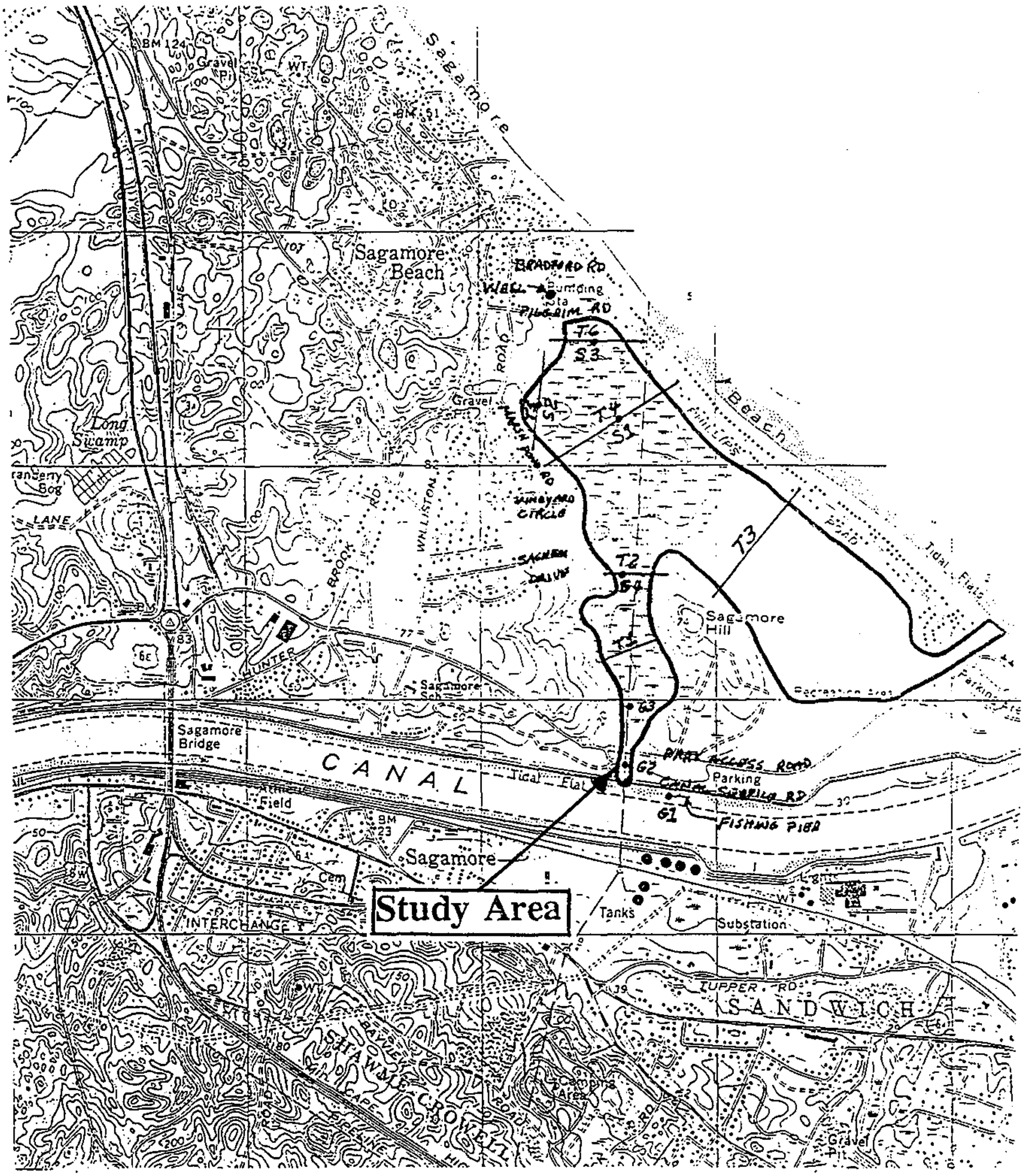
The culvert installation should be performed from fall through spring when the Canal Service Road and Scusset Beach Road are subject to the least amount of traffic. During the construction of the culvert under Scusset Beach Road a temporary bypass road should be constructed between the Canal Access Road and Scusset Beach Road across the channel to be utilized during the construction period of both roads. This road should be constructed in a way to minimize the filling of the channel. The materials for the bypass road will be contractor furnished.

Existing utilities run the length of Scusset Beach Road. Protection of a waterline and a fiber-optic cable will have to be considered for culvert construction.

The recommended foundation system for the culvert and flood gates is a minimum of 3 feet of compacted gravel fill bearing on naturally occurring, undisturbed, inorganic soils. The gravel fill should be placed in the dry.

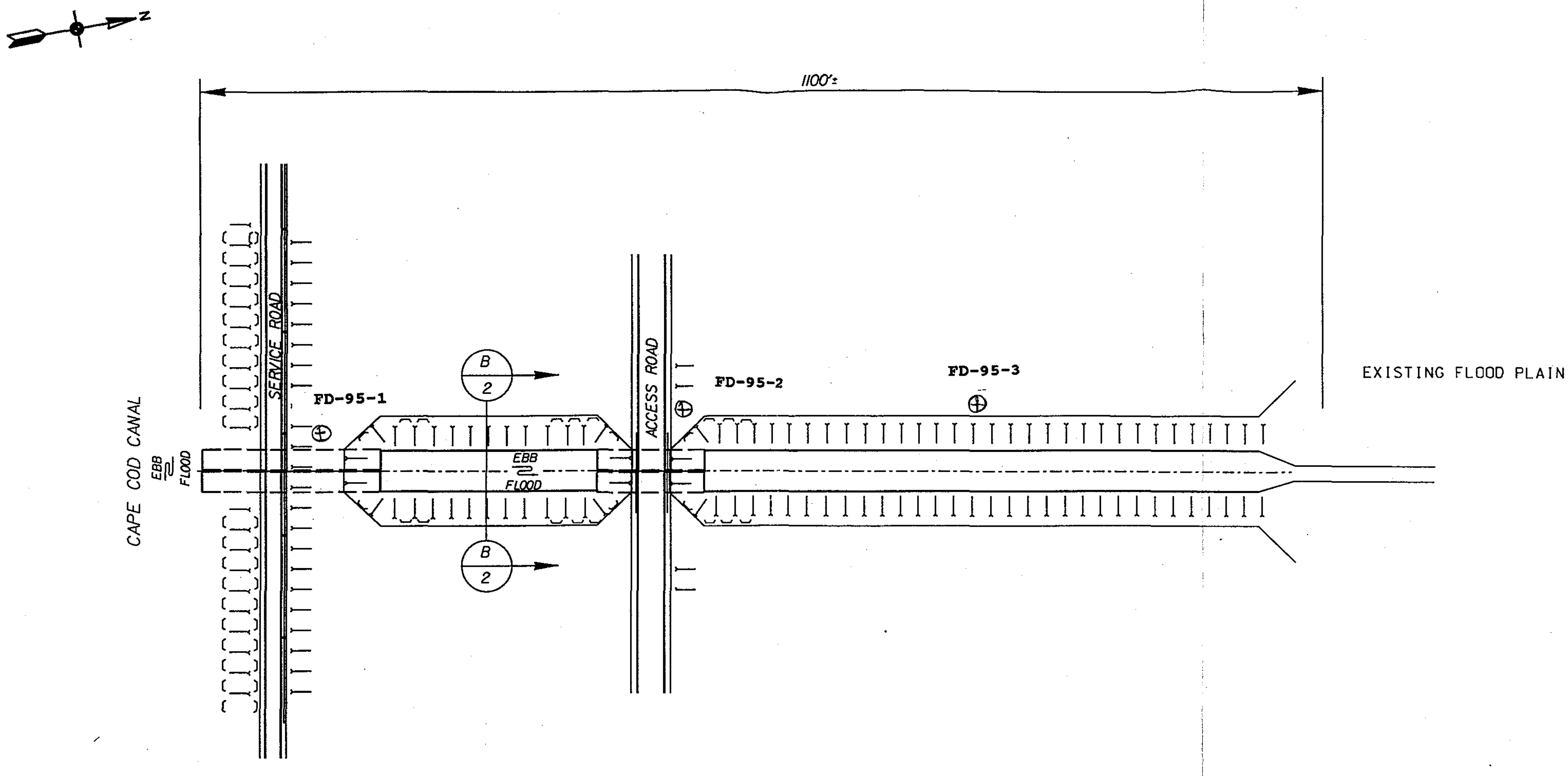
The water velocities through the culvert necessitate slope protection on the embankment around the culvert. Stone protection with a bedding layer is required. Filter criteria should be incorporated as necessary when designing the slope protection.

APPENDIX A



Sagamore Marsh Restoration Feasibility Study

Figure 1



PROPOSED WIDENING PLAN

SCALE: 1"=100'

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

SAGAMORE MARSH RESTORATION
CAPE COD CANAL, MA
SAGAMORE MARSH

Plan of Explorations **Figure 2**

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U.S. ARMY

PAGE

SUBJECT Sagamore Salt Marsh

COMPUTATION

COMPUTED BY MEI   CHECKED BY   DATE 7/18

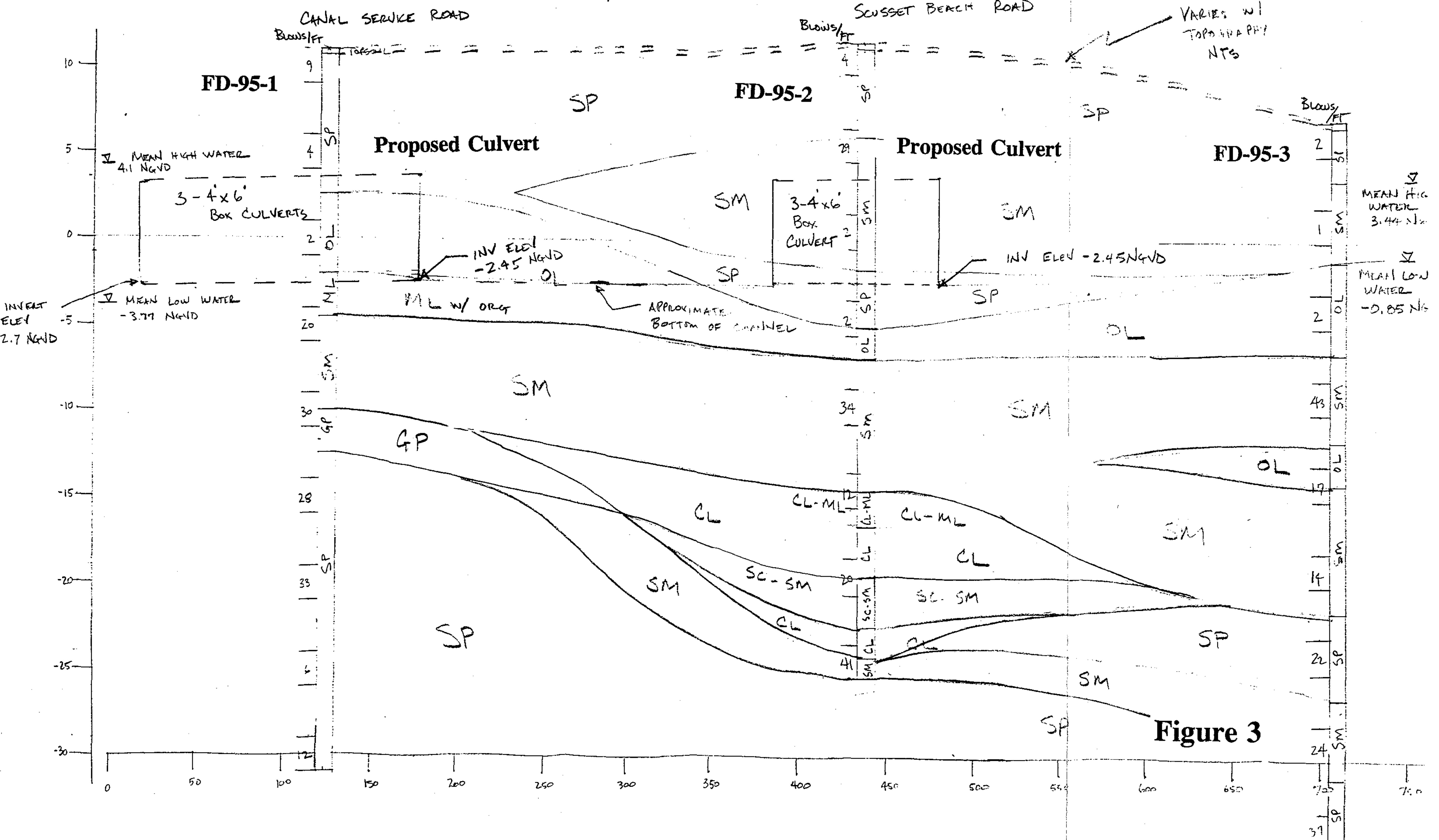


Figure 3

NED FORM 223
27 Sept 49

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PAGE

SUBJECT: SAGAMORE MARSH RESTORATION
COMPUTATION: CANAL SERVICE ROAD
COMPUTED BY: MEI CHECKED BY: DATE: 7/18/95

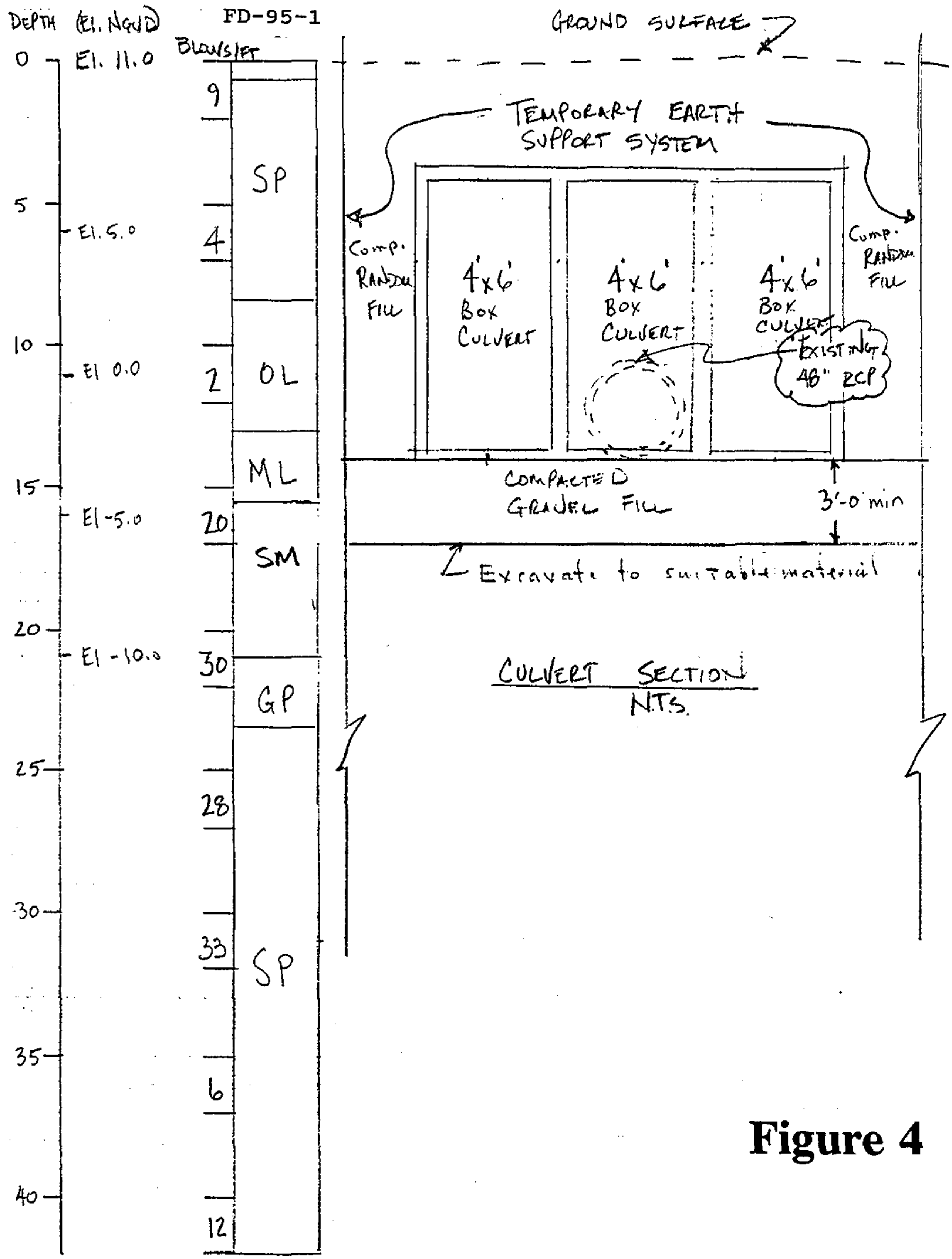

Figure 4

Detail of Culvert with Temporary Earth Support System

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PAGE

SUBJECT Sagamore Marsh Restoration

COMPUTATION Scusset Beach Road

COMPUTED BY M.E.I. CHECKED BY DATE 7/18/95

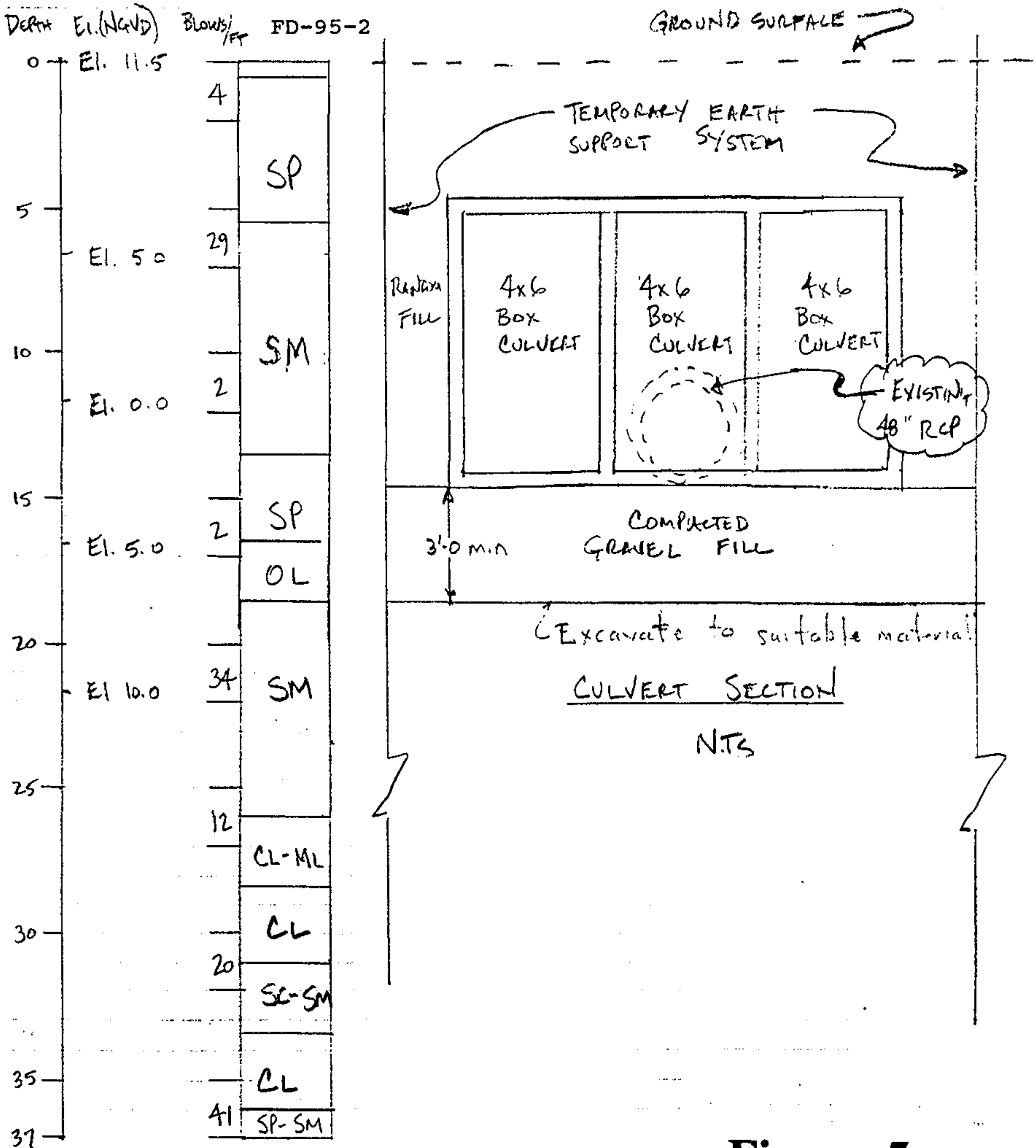

Figure 5

Detail of Culvert with Temporary Earth Support System

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NED FORM 223
27 Sept 49

SUBJECT

COMPUTATION

COMPUTED BY

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DATE

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STONE PROTECTION FOR DRAINAGE CHANNEL

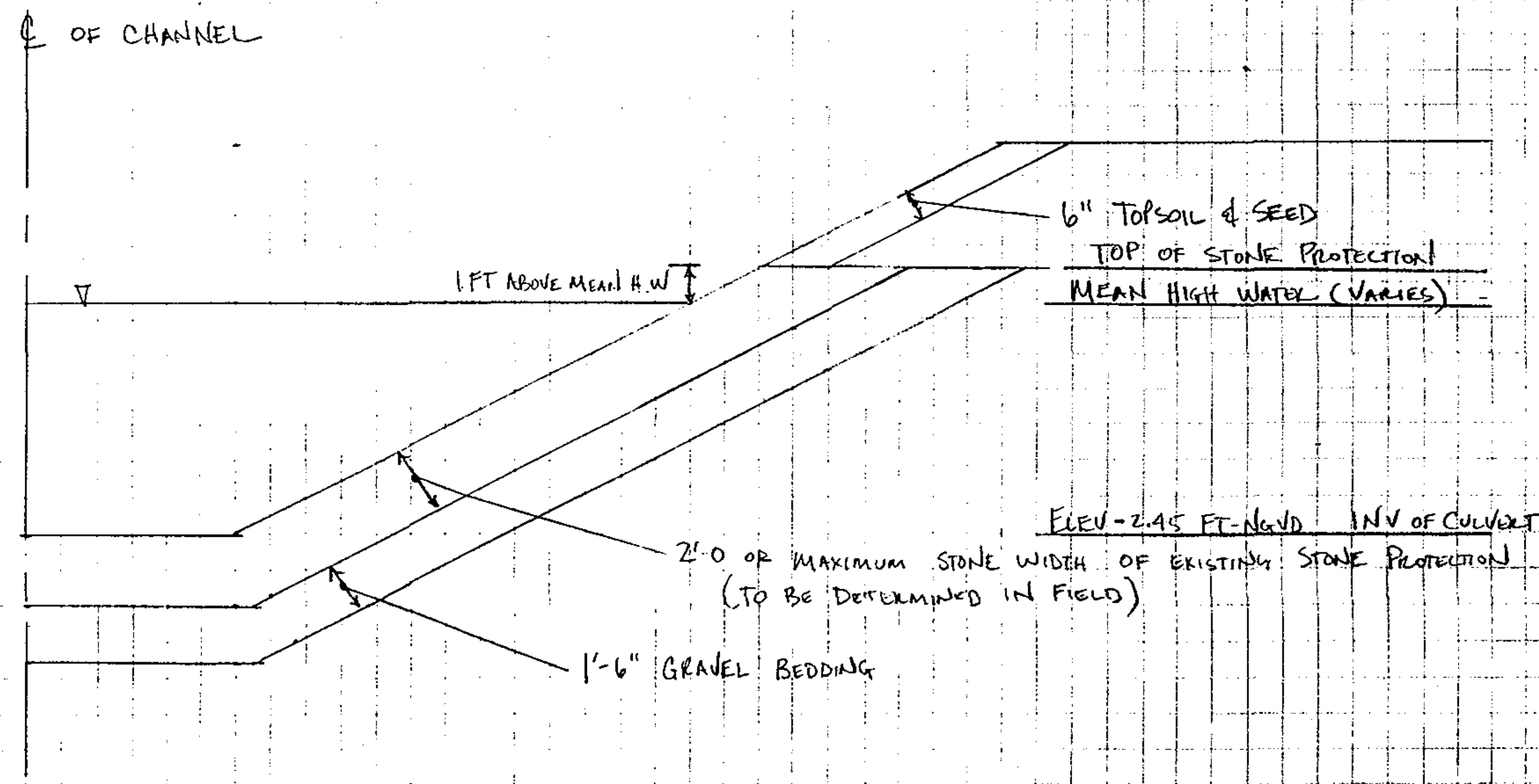

FIGURE 6

APPENDIX E

GROUNDWATER ANALYSIS

Hydrogeology and Analysis of Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts

U.S. Geological Survey
Water-Resources Investigations Report 96-4200

Prepared in cooperation with the
U.S. ARMY CORPS OF ENGINEERS

Hydrogeology and Analysis of Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts

By DONALD A. WALTER, JOHN P. MASTERSON, and PAUL M. BARLOW

U.S. Geological Survey
Water-Resources Investigations Report 96-4200

Prepared in cooperation with the
U.S. ARMY CORPS OF ENGINEERS

Marlborough, Massachusetts
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

Chief, Massachusetts-Rhode Island District
U.S. Geological Survey
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Marlborough, MA 01752

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNITS

CONVERSION FACTORS

Multiply	by	To obtain
acre	4,047	square meter
cubic foot per day (ft^3/s)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter square per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer
million gallons (Mgal)	3.785	million liters
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square foot per day (ft^2/d)	0.09290	square meter per day
square mile (mi^2)	2.590	square kilometer

Air temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

°C = (°F-32)/1.8.

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic vertical datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level of 1929.

WATER-QUALITY UNITS

Chemical concentration is given in units of milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams and micrograms per liter are units expressing the mass of the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. Micrograms per liter is equivalent to "parts per billion." Milligrams per liter is equivalent to "parts per million." Chemical concentration is also given in units of milligrams per kilograms (mg/kg). One milligram per kilogram is equivalent to 1 microgram per gram. Milligram per kilogram is equivalent to "parts per million."

Hydrogeology and Analysis of Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts

By Donald A. Walter, John P. Masterson, *and* Paul M. Barlow

Abstract

A study of the hydrogeology and an analysis of the ground-water-flow system near Sagamore Marsh, southeastern Massachusetts, was undertaken to improve the understanding of the current (1994-95) hydrogeologic conditions near the marsh and how the ground-water system might respond to proposed changes in the tidal-stage regime of streams that flood and drain the marsh. Sagamore Marsh is in a coastal area that is bounded to the east by Cape Cod Bay and to the south by the Cape Cod Canal. The regional geology is characterized by deltaic and glaciolacustrine sediments. The sediments consist of gravel, sand, silt, and clay and are part of the Plymouth-Carver regional aquifer system. The glacial sediments are bounded laterally by marine sand, silt, and clay along the coast. The principal aquifer in the area consists of fine to coarse glacial sand and is locally confined by fine-grained glaciolacustrine deposits consisting of silt and sandy clay and fine-grained salt-marsh sediments consisting of peat and clay. The aquifer is underlain by finer grained glaciolacustrine sediments in upland areas and by marine clay along the coast.

Shallow ground water discharges primarily along the edge of the marsh, whereas deeper ground water flows beneath the marsh and discharges to Cape Cod Bay. Tidal pulses originating from Cape Cod Bay and from tidal channels in the marsh are rapidly attenuated in the subsurface. Tidal ranges in Cape Cod Bay and in the tidal channels were on the order of 9 and 1.5 feet, respectively, whereas tidal ranges in the ground-water levels were less than 0.2 foot. Tidal pulses measured in the water table beneath a barrier beach between the marsh and Cape Cod Bay were more in phase with tidal pulses from Cape Cod Bay than with tidal pulses from the tidal channels in Sagamore Marsh, whereas tidal pulses in the regional aquifer were more in phase with tidal pulses from the tidal channels.

A 5-day aquifer test at a public-supply well adjacent to the marsh gave a transmissivity of the regional aquifer of 9,300 to 10,900 feet squared per day and a hydraulic conductivity of 181 to 213 feet per day, assuming a saturated thickness of the aquifer of 51.3 feet. The regional aquifer became unconfined near the pumped well during the test. The ratio of tidal ranges in the tidal channel to the ranges in the underlying aquifer at two sites (the lower and upper marsh) indicated aquifer diffusivities for the marsh sediments of 380 and 170 feet squared per day; these values correspond to hydraulic conductivities of 2.5×10^{-3} and 1.7×10^{-3} feet per day, respectively. The maximum distances from the tidal channel at the lower and upper marsh sites where tidal ranges would exceed 0.01 foot, as calculated from aquifer diffusivities and current (1995) tidal ranges in the tidal channels, were 24.4 and 26.7 feet, respectively. The maximum distances from the tidal channel where tidal pulses in the ground water would exceed 0.01 foot, using potential increased tidal stages resulting from proposed tidal-stage modifications and predicted by the U.S. Army Corps of Engineers, were 37.1 and 42.0 feet, respectively.

A numerical model of the marsh and surrounding aquifer system indicated that the contributing area for the supply well adjacent to the marsh, for current (1994) pumping conditions, extends toward Great Herring Pond, about 2 miles northwest (upgradient) of the well, and does not extend beneath the marsh. The model also indicates that the predicted increases in tidal stages in the marsh will have a negligible effect on local ground-water levels.

INTRODUCTION

Sagamore Marsh is a salt marsh in the coastal area of southeastern Massachusetts that is bounded to the east by Cape Cod Bay and to the south by the Cape Cod Canal (fig. 1). The construction and maintenance of the Cape Cod Canal from 1883 until the late 1930's greatly altered the geography, hydrology, and ecology of the marsh; the primary result of canal construction and maintenance was a reversal in tidal-flow directions in the marsh and a decrease in the amount of saltwater flowing into the marsh (Carlisle, 1994). Predevelopment drainage in the marsh was to the east into Cape Cod Bay through a tidal channel known as the Scusset River. Sediments from canal dredging and natural long-shore sediment transport effectively closed the Scusset River in 1932, and inputs of fresh surface water and precipitation resulted in the formation of a large body of ponded freshwater in the marsh. A trench cut between the marsh and the canal in the early 1930's caused the ponded water to drain and allowed saltwater to enter the marsh from the south. At present, saltwater enters the marsh through a 4-foot diameter culvert at the canal. The present-day ecology of the marsh was investigated by Oliver and Swain (1994). Carlisle (1994) discusses in detail the history of development in and around Sagamore Marsh as well as the current ecology, geography, and hydrology of the marsh. The hydraulics of salt-marsh sediments are discussed by Knott and others (1987). The ecology and evolution of New England salt marshes are discussed in detail by Nixon (1982) and Teal (1986).

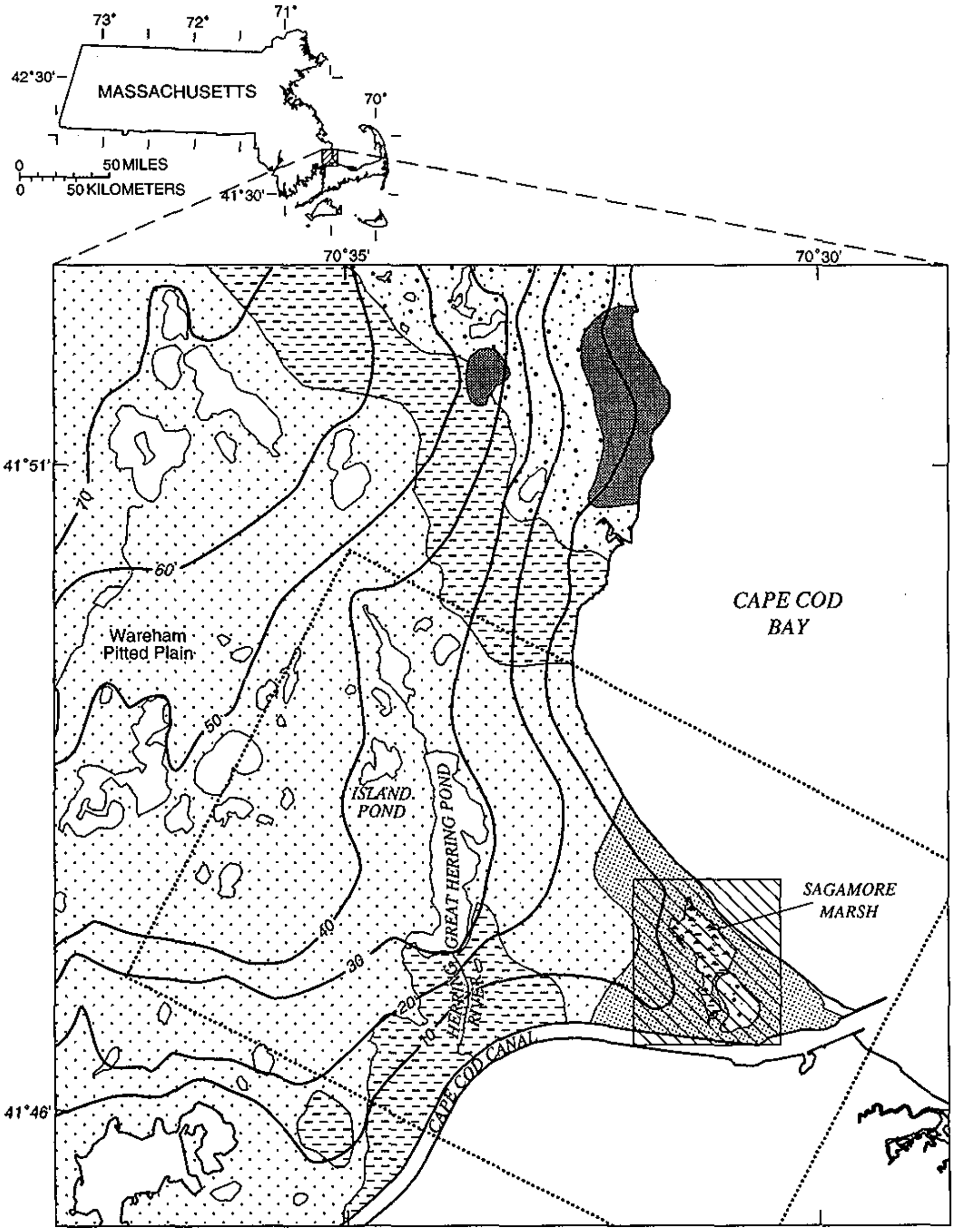
Sagamore Marsh, which currently encompasses an area of about 300 acres, is predominantly a brackish-water marsh that is dominated by common reed (*Phragmites australis*); lower parts of the marsh regularly receive overbank flooding and are dominated by salt-marsh cord grass (*Spartina alterniflora*). *Phragmites* vegetation can tolerate salinities as much as 20,000 mg/L and is commonly associated with brackish-water marshes. This species is typically found along the edges of healthy salt marshes and can invade marsh interiors only when salinities are decreased.

In an effort to restore salt-marsh and estuarine habitat in Sagamore Marsh, the U.S. Army Corps of Engineers (USACE) has proposed to increase the amount of saltwater that enters the marsh by increasing the size of the culvert between the Cape Cod Canal and the marsh. The increase in salt-water inflow will increase the range of tidal fluctuations in the marsh channels and will result in increased overbank flooding at high tide in parts of the marsh; overbank flooding will increase salinities sufficiently to allow salt-marsh vegetation to replace the *Phragmites*. The proposed salt-marsh restoration is anticipated to restore about 50 acres of degraded marsh (Matthew Walsh, U.S. Army Corps of Engineers, oral commun., 1995).

Existing data are limited regarding the hydrogeologic framework and the ground-water-flow system in the area around Sagamore Marsh. In April 1995, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, began an investigation into the geology and ground-water hydrology of the Sagamore Marsh area to improve the understanding of the local hydrogeologic framework and ground-water-flow system and to address issues regarding the potential effects of the proposed marsh-restoration project on the local ground-water system. The investigation was done in part to determine whether the proposed increase in the amount of saltwater entering the marsh at high tide would be likely to increase hydraulic heads in the underlying aquifer, which could affect septic systems near the marsh. The investigation also was done to determine whether the proposed restoration of the marsh would be likely to cause saltwater intrusion into the aquifer, which is the source of water for a large-capacity public-supply well adjacent to the marsh. The extent of the study area is shown in figure 1 and includes a total area of about 27.2 mi^2; the study area corresponds to the part of the regional aquifer that was assessed using a ground-water-flow model. Data were collected in a 2.0 mi^2 area in and near the marsh, which is shown as the field study area in figure 1.

Purpose and Scope

The purpose of this report is to describe the hydrogeology and ground-water-flow system of the Sagamore Marsh area and to evaluate possible changes in the flow system caused by increased tidal stages in the tidal channels. Specifically, the report discusses (1) the stratigraphy of hydrogeologic units in the Sagamore Marsh area; (2) the patterns of ground-water flow and the effects of ground-water pumping and tidal fluctuations on the ground-water-flow system near the marsh; (3) the delineation of the zone of contribution and source of water for a public-supply well adjacent to the marsh; and (4) how the ground-water-flow system may respond to increased tidal stages in the marsh. The report also includes the results of analytical- and numerical-modeling analyses of the ground-water-flow system.



Base from U.S. Geological Survey digital data
1:24,000, 1991
Universal Transverse Mercator projection
Zone 19

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

SURFICIAL GEOLOGY
- Outwash
- Moraine
- Kame
- *Till*
- Glaciolacustrine deposits

GEOLOGIC CONTACT

AREA OF FIELD STUDY-- A detailed map is shown in figure 2

BOUNDARY OF STUDY AREA--Boundary is coincident with the boundary of the finite-difference model grid shown in figure 13

—10— WATER-TABLE CONTOUR--Shows altitude of water table (from Hansen and Lapham, 1992). Contour interval is 10 feet. Datum is sea level

Figure 1. Location of Sagamore Marsh study area, regional water table, and surficial geology of Plymouth-Carver Aquifer, southeastern Massachusetts.

Regional Physiographic, Geologic, and Hydrologic Setting

The regional geology and hydrology of southeastern Massachusetts have been investigated previously by Frimpter (1973), Williams and Tasker (1974), and Hansen and Lapham (1992). Southeastern Massachusetts is in the Coastal Lowlands physiographic province of New England. Land surface is characterized by knob and kettle topography associated with glacial moraines and flat, gently sloping topography associated with glacial outwash plains. Land-surface altitudes range from 250 ft above sea level in the northwestern part of the Plymouth-Carver area to sea level along the coast.

The study area is at the southeastern edge of a glacial aquifer system known as the Plymouth-Carver aquifer (fig. 1). The aquifer system, which encompasses an area of about 140 mi^2 in southeastern Massachusetts, includes several aquifers and confining units. A detailed analysis of the ground-water-flow system in the Plymouth-Carver aquifer is reported in Hansen and Lapham (1992). The aquifer system consists of unconsolidated glacial sand, silt, and clay that was deposited during the Wisconsin Stage of the Pleistocene Epoch (Mather, 1952). Depositional environments for the glacial sediments include moraines, fluvial outwash plains, and glacial lakes. The marsh is near the southeastern edge the Wareham Pitted Plain. This area is a gently sloping plain with numerous kettle holes and ponds. The Wareham Pitted Plain represents a large fluvial outwash plain that formed to the south of the retreating Laurentide ice sheet, about 15,000 years ago. The sediment source lies to the northwest of the plain near the Hog Rock and Ellisville moraines. The glacial outwash deposits consist primarily of stratified sand and gravel and frequently show a fining-downward sequence. The surficial outwash deposits grade laterally to finer grained glaciolacustrine deposits in the area around Sagamore Marsh; these sediments were deposited in a proglacial lake that may be associated with the Wareham Pitted Plain outwash deposits (B.D. Stone, U.S. Geological Survey, oral commun., 1995).

Ground-water levels in the Plymouth-Carver aquifer range from about 125 ft above sea level at the top of the water-table mound to the northwest of the Sagamore Marsh area to sea level at the coast (Hansen and Lapham, 1992). Near Sagamore Marsh, ground-water levels range from about 10 ft above sea level near the western edge of the marsh to sea level at the coast. The regional ground-water-flow system receives about 24 to 27 in. of recharge annually from direct infiltration of precipitation (Hansen and Lapham, 1992). Ground-water flows radially outward from the center of the aquifer system (at the top of the water-table mound) and discharges to Cape Cod Bay, Cape Cod Canal, and coastal embayments and tidal creeks, including those of Sagamore Marsh. Regional ground-water flow in the study area is to the southeast; water-table altitudes in the southeastern part of the aquifer are shown in figure 1.

The regional aquifer system generally is unconfined; however, confined and semiconfined conditions do occur locally. Where the aquifer is confined (or semiconfined), the vertical movement of water is restricted by overlying deposits of low vertical and horizontal hydraulic conductivity. Ground-water flow in the southeastern part of the aquifer system is greatly affected by Great Herring Pond (fig. 1). The 376-acre pond, which is about 2 mi northwest of Sagamore Marsh, has an average depth of about 20 ft, a maximum depth of about 40 ft, and a surface altitude of about 34 ft (Massachusetts Division of Fisheries and Wildlife, 1993).

Estimates of average horizontal hydraulic conductivity of stratified sand and gravel deposits of the Plymouth-Carver aquifer system, based on the analysis of 33 aquifer tests done for public and industrial supplies and lithologic data from test well sites, ranged from 55 to 313 ft/d, with a mean of 188 ft/d (Hansen and Lapham, 1992). Hansen and Lapham (1992) reported that horizontal hydraulic conductivities of till deposits in the Plymouth-Carver aquifer system ranged from 10 to 100 ft/d. Specific yield of the unconfined aquifer system, estimated from the results of 22 aquifer tests, ranged from 0.02 to 0.35, with a mean of 0.16.

The Plymouth-Carver aquifer system is underlain by crystalline bedrock. The bedrock surface ranges from an altitude of 100 ft above sea level in the western part of the aquifer to 200 ft below sea level in the southeastern part of the aquifer. A narrow, northwest-southeast trending bedrock valley transects the southeastern part of the aquifer; bedrock-surface altitudes in the valley are more than 200 ft below sea level (Hansen and Lapham, 1992).

Acknowledgments

The authors appreciate the assistance of several property owners near the Sagamore Marsh who provided access to the marsh and allowed the installation of drive points and (or) observation wells on their property. The assistance of Peter Phippen and William Salomma, Massachusetts Department of Environmental Management and of Paul Gibbs and Sean Anderson, North Sagamore Water District during the aquifer test, also are appreciated.

METHODS OF INVESTIGATION

A network of 12 observation wells, 9 drive points, and 3 tidal-channel stilling wells was installed in and around Sagamore Marsh (fig. 2). The wells were installed near an existing public supply well, which was included in the monitoring network. Physical data for all sites used in the study are presented in table 1. The 2.5-inch PVC (polyvinylchloride) observation wells were installed using a hollow-stem auger drill rig. The 0.75-inch steel drive points were installed using a hand-operated sliding hammer, and the 2.5-inch PVC stilling wells were installed using a hand-operated steel hammer. Field methods used in the installation of drive points and the collection of marsh-sediment cores are those described by Weiskel and others (1995).

A 5-day aquifer test was done in June 1995 to determine the response of the ground-water-flow system near the marsh to pumping of the large-capacity public-supply well BHW013 (known as the North Sagamore Water District Beach Well) and to determine the hydraulic properties of the regional aquifer near the marsh. Ten of the 12 observation wells and the supply well were instrumented with Drucks[1] pressure transducers to continuously measure water levels during the 5-day pumping phase and the 5-day recovery phase of the test.

Water-level data from the network of wells, drive points, and stilling wells were used to map the water table and the potentiometric surface in the Sagamore Marsh area and to assess the effects of tidal fluctuations in the marsh tidal channels and Cape Cod Bay on ground-water levels in and around the marsh. Ground-water levels at all sites were measured during a 3-hour period (within 1.5 hours of high tide) in June 1995 using a hand-operated electric tape. Six of the nine drive points and the three tidal-channel stilling wells were instrumented with Drucks pressure transducers to continuously measure tidal-related water-level fluctuations in the marsh tidal channels and in the ground water from June 29 through July 18, 1995.

Lithologic data collected during the study and the results of the aquifer test were used to develop a steady-state, finite-difference ground-water-flow model of the Sagamore Marsh area. The USGS numerical model MODFLOW (McDonald and Harbaugh, 1988) and the particle-tracking program MODPATH (Pollock, 1994) were used in the analysis. The model was used to determine the contributing area of well BHW013 and to estimate marsh-restoration-related changes in high tide ground-water levels around the marsh. An existing finite-difference model of the regional Plymouth-Carver aquifer system (Hansen and Lapham, 1992) was used to estimate boundary conditions and regional hydrogeologic conditions for the model developed for the Sagamore Marsh area.

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[1]Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

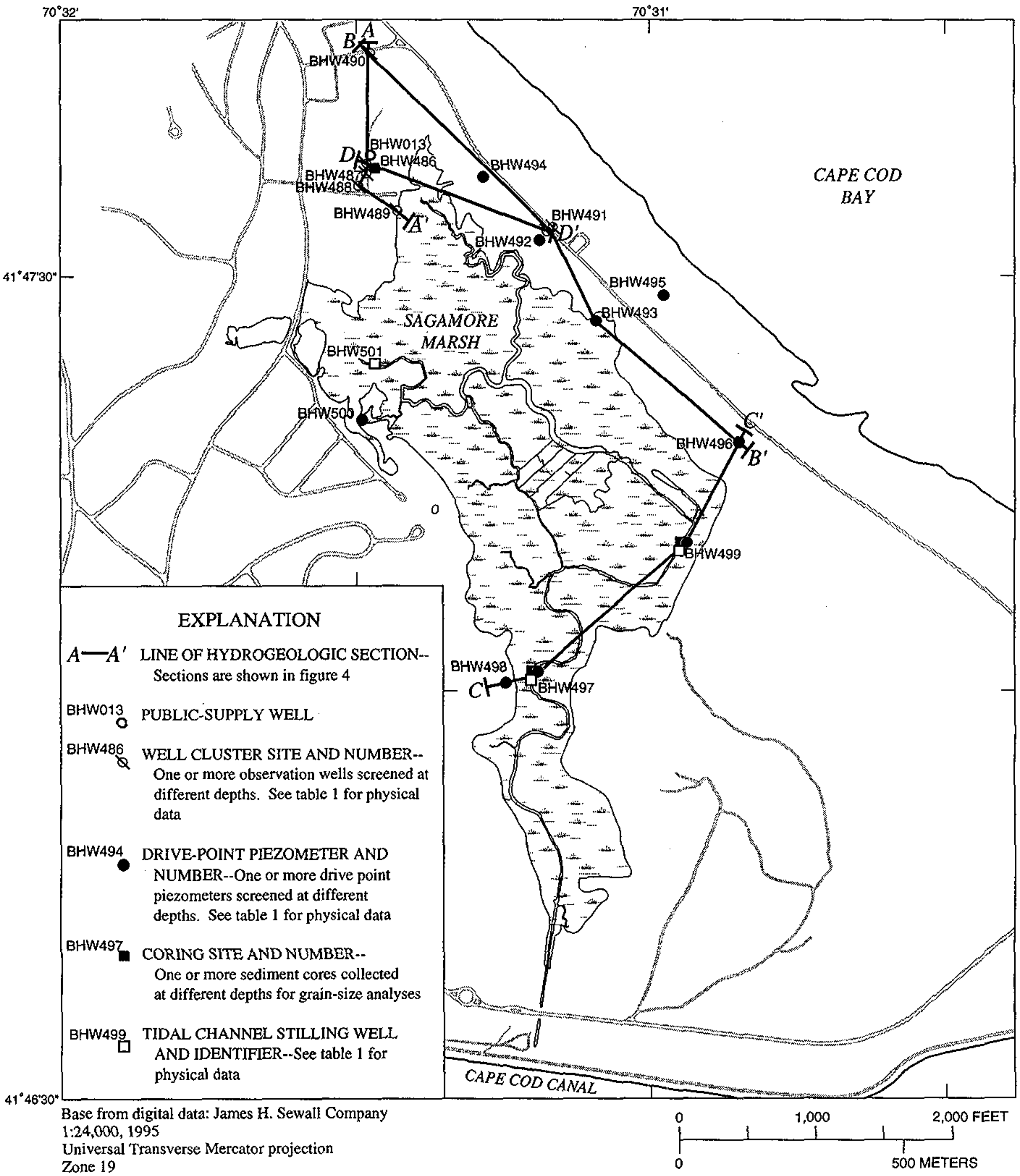


Figure 2. Location of wells, drive points, coring sites, and stilling wells used for data collection and location of geologic sections near Sagamore Marsh, southeastern Massachusetts.

Table 1. Physical data for observation wells, drive points, and stilling wells used for collection of hydrologic data, near Sagamore Marsh, southeastern Massachusetts

[Site identifier: Location of sites shown in figure 2. Type: Supply, 10.0-inch diameter steel well; well, 2.5-inch diameter PVC polyvinylchloride well; DP, 0.75-inch diameter steel drive point; tidal, 2.5-inch diameter PVC tidal channel stilling well. Latitude/Longitude given in degrees, minutes, and seconds. Altitudes are in feet above or below (-) sea level. ft, foot]

Site identifier	Well depth (ft)	Type	Latitude	Longitude	Altitude of land surface	Altitude of top of screen	Altitude of bottom of screen	Remarks
BHW013	54	Supply	414735	0703131	12.29	-32.71	-40.71	--
BHW486	15	Well	414734	0703131	16.26	8.81	3.81	Split-spoon cores taken at depths of 175 ft below land surface. Natural gamma and electromagnetic induction logs collected.
	55	Well	414734	0703131	16.18	-33.18	-35.18	
	175	Well	414734	0703131	16.23	-152.47	-154.47	
BHW487	15	Well	414733	0703131	17.81	9.49	4.49	Natural gamma and electromagnetic induction logs collected.
	52	Well	414733	0703131	18.12	-32.22	-34.22	
BHW488	13	Well	414733	0703132	17.59	10.15	5.15	Do.
	53	Well	414732	0703132	17.50	-30.87	-32.87	
BHW489	10	Well	414731	0703128	10.28	6.48	1.48	Do.
	49	Well	414731	0703128	10.45	-37.05	-39.05	
BHW490	150	Well	414743	0703131	10.18	-19.62	-21.62	Do.
BHW491	7	Well	414729	0703113	6.48	6.45	1.45	Do.
	55	Well	414729	0703113	6.29	-44.69	-46.69	
BHW492	5	DP	414729	0703114	4.78	1.14	.14	Continuous core samples collected at a depth of 4-8 ft below land surface. Hand-operated sand-coring tool was used.
BHW493	5	DP	414723	0703109	3.69	-.22	-1.22	Do.
BHW494	5	DP	414733	0703121	5.24	1.71	.71	Do.
BHW495	5	DP	414724	0703103	11.22	8.41	7.41	Do.
BHW496	5	DP	414714	0703056	4.45	1.42	.42	Do.
BHW497	3	Tidal	414657	0703116	--	1.90	-.10	Continuous core samples collected at a depth of 20 ft below land surface. Hand-operated peat-coring tool was used.
	19	DP	414657	0703116	2.88	-16.48	-17.48	
BHW498	5	DP	414656	0703119	4.63	.51	-.49	Continuous core samples collected at a depth of 4-8 ft below land surface. Hand-operated sand-coring tool was used.
BHW499	3	Tidal	414706	0703101	--	2.84	.84	Continuous core samples collected at a depth of 20 ft below land surface. Hand-operated peat-coring tool was used.
	21	DP	414706	0703101	2.81	-22.46	-23.46	
BHW500	5	DP	414715	0703133	4.50	2.50	1.50	Continuous core samples collected at a depth of 4-8 ft below land surface. Hand-operated sand-coring tool was used.
BHW501	3	Tidal	414720	0703131	--	1.01	-.99	--

HYDROGEOLOGY

Sagamore Marsh is at the edge of a large, complex glacial aquifer system that is laterally bounded by marine sediments along the coast. Ground-water flow, which is locally confined, generally is to the southeast and water levels in the aquifer are affected by nearby Cape Cod Bay and the Cape Cod Canal. Lithologic and hydrologic data collected during this investigation were used to develop a better understanding of the local ground-water-flow system near Sagamore Marsh.

Hydrogeologic Units

Sagamore Marsh is bounded to the west and southeast by glacial upland terrain, to the east by artificial fill related to construction of the Cape Cod Canal, and to the northeast by a barrier beach. Lithologic data from core samples and drillers logs and natural gamma logs were used to determine the hydrogeologic framework of the glacial, marine, and marsh sediments in the Sagamore Marsh area.

Glacial Sediments

Geophysical and lithologic data indicate that glacial sediments at site BHW486 consist of four major lithologic stratigraphic units. The split-spoon core samples and the natural gamma log show a fine-grained confining unit that extends from land surface (18 ft above sea level) to an altitude of about 2 ft above sea level (fig. 3). The lithologic unit consists of brown silt and sandy clay that probably represent Lake Cape Cod glaciolacustrine deposits (Oldale and Barlow, 1986); these sediments were deposited in a large pro-glacial lake that formed north of present-day Cape Cod. The lithologic unit underlying the silt and clay consists of fine to coarse brown sand with some gravel and extends to about 45 ft below sea level. This sediment probably represents coarser grained deltaic deposits related to deposition in Lake Cape Cod (B.D. Stone, oral commun., 1995). The lithology of the unit underlying the sand aquifer is highly variable from an altitude of 45 to 102 ft below sea level. The unit is characterized by interbedded gravel, fine to coarse sand, silt, and clay. The clay and silt layers, which are brown or gray in color, commonly contain large cobbles. Sandy layers, which typically are dense and compact, range in color from red and brown to black. This unit probably represents glaciolacustrine deposits associated with deltaic deposits of the Wareham Pitted Plain (B.D. Stone, oral commun., 1995), which lies to the northwest of the study area. The highly variable unit is underlain by very fine to fine gray sand and silt that extends to the bottom of the borehole at 160 ft below sea level. This unit is glaciolacustrine in origin and probably also is associated with the deltaic deposits of the Wareham Pitted Plain. The Sagamore Marsh area is within a southeast-trending valley in the underlying bedrock surface.

The stratigraphic units at site BHW486 correspond to four major hydrogeologic units. The first hydrogeologic unit, which is the brown silt and sandy clay associated with Cape Cod Lake deposits, is a confining unit near land surface; the water table is within this unit at site BHW486. This confining unit is underlain by fine to coarse brown deltaic sand that comprises the second hydrogeologic unit. This sand unit has the most favorable water-transmitting properties in the stratigraphic column at the site and comprises the major aquifer in the area around the marsh. A nearby public-supply well, BHW013, is screened in the sand unit at a depth of 33 to 41 ft below sea level. The third hydrogeologic unit is the interbedded gravel, sand, silt, and clay unit and the fourth hydrogeologic unit is the fine gray silty sand unit; both of these lower units are associated with Wareham Pitted Plain glaciolacustrine deposits. Although the interbedded sand, silt, and clay unit probably has greater water-transmitting properties than the fine sand and silt unit, both have relatively poor water-transmitting properties and probably are not important aquifers in the area.

The stratigraphy of the glacial sediments along the northwestern side of the marsh is shown in figure 4*A*. Lithologic data and natural gamma logs indicate that the brown silt and sandy clay were near the surface at sites BHW486, BHW487, and BHW488, but not at site BHW489, suggesting that the confining unit may be discontinuous; sandy clay also was at the surface along the western edge of the marsh at sites BHW498 and BHW500 (fig. 2) to the south of section *A-A'*. Natural gamma logs indicate that the sand aquifer underlying the confining unit contains some finer grained material at sites BHW489 and BHW490. A contact between marine and glacial sediments was at an altitude of about 25 ft below land surface at site BHW490 near Cape Cod Bay. The marine sediments consisted of fine to medium gray sand with interbedded gray clayey peat.

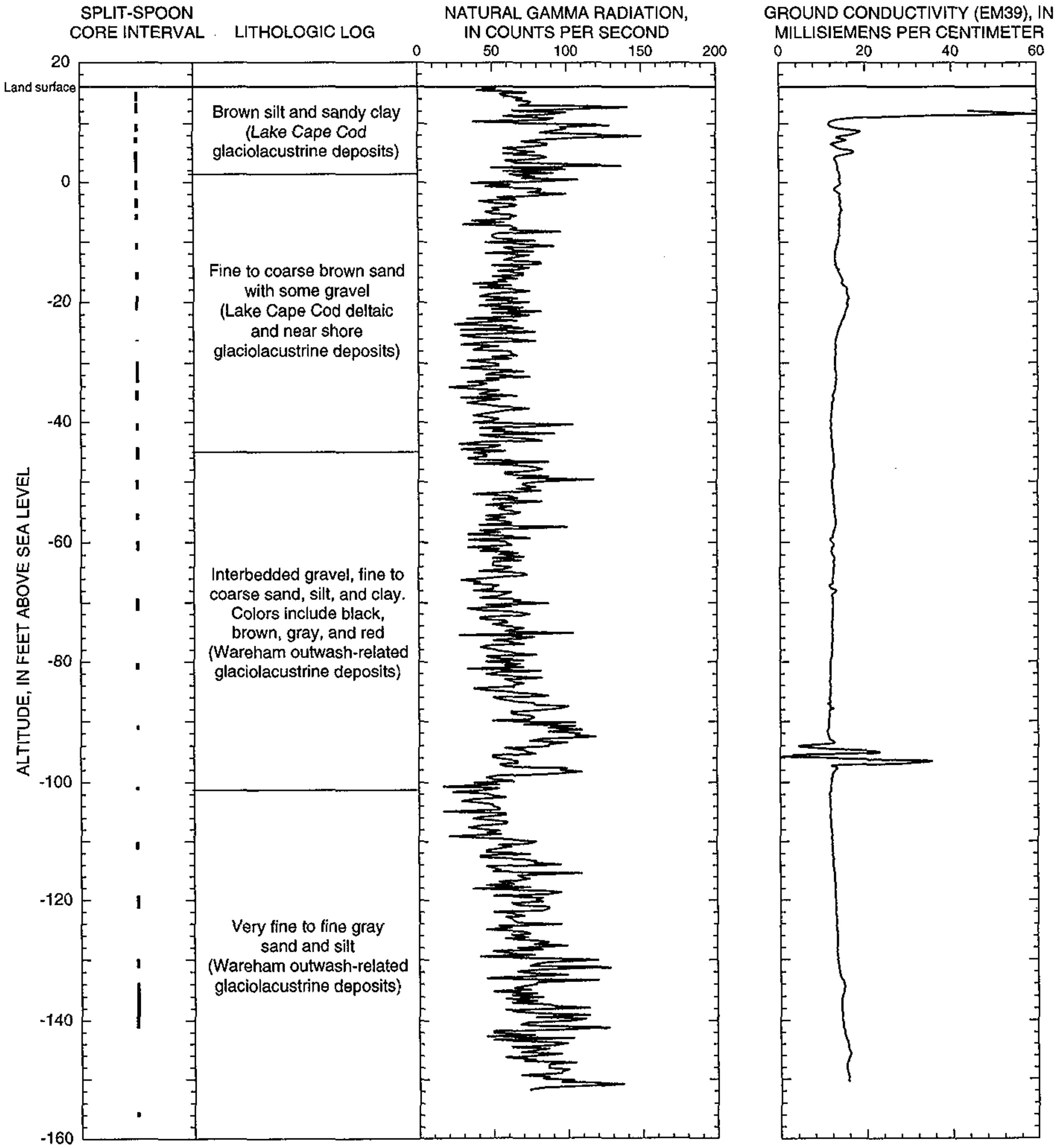
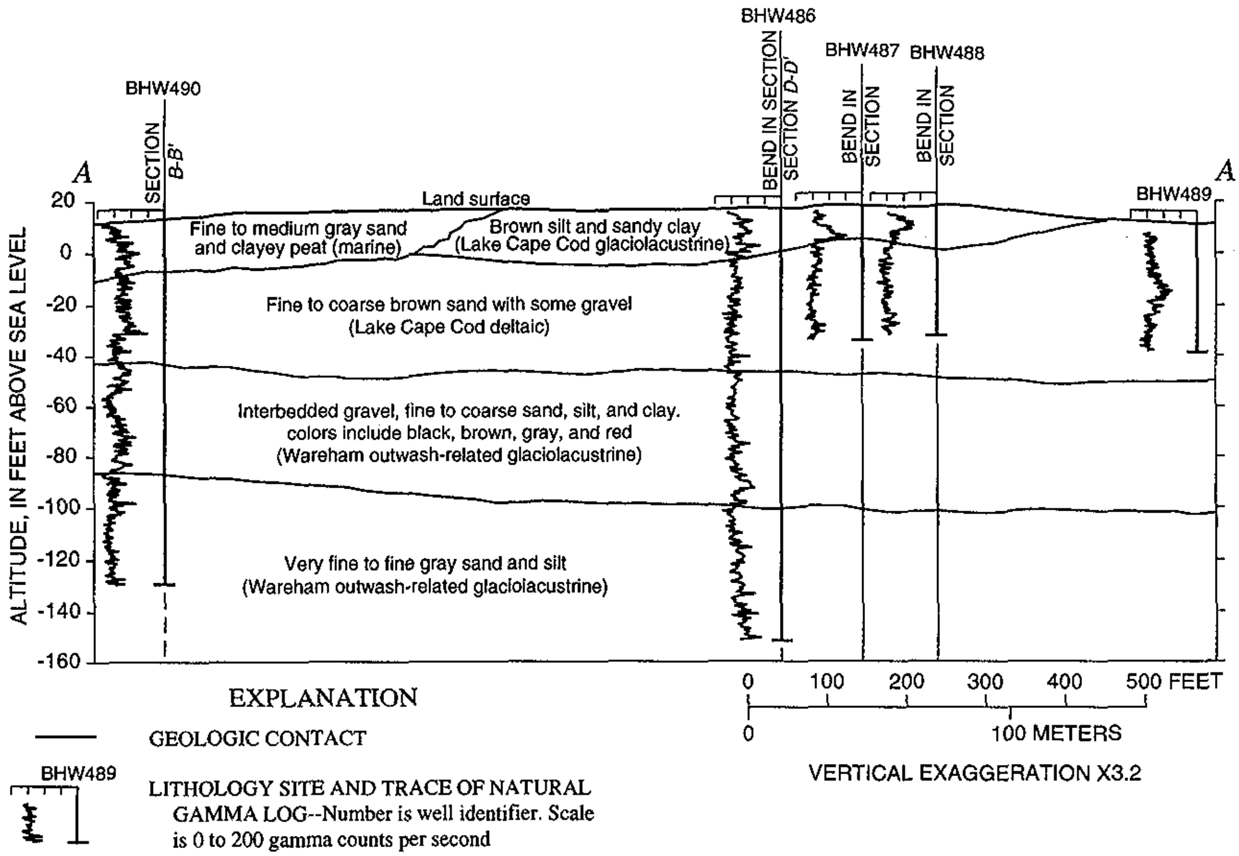


Figure 3. Natural gamma, ground conductivity (EM39), and lithologic logs for site BHW486 near Sagamore Marsh, southeastern Massachusetts.



***A*. Section *A-A'*.**

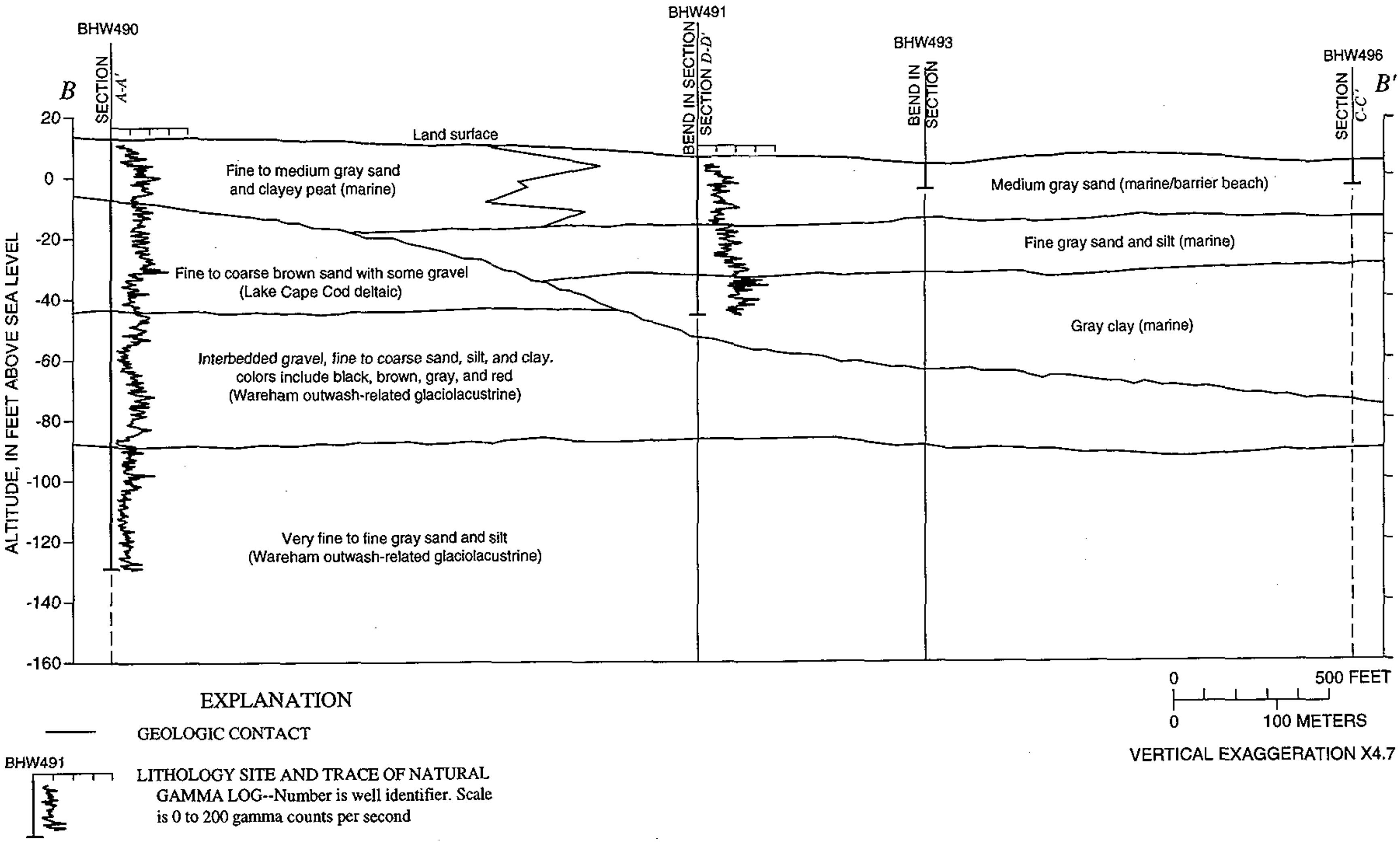
Figure 4. Stratigraphy of major hydrogeologic units in the Sagamore Marsh area along (*A*) section *A-A'*, (*B*) section *B-B'*, (*C*) section *C-C'*, and (*D*) section *D-D'*, southeastern Massachusetts. (Lines of sections are shown in figure 2.)

Marine Sediments

Stratigraphy along the northeastern edge of the marsh is shown in figure 4*B*; this section lies along the marsh side of the barrier beach. Gray marine sand was observed near the surface at all sites along the section. Gamma and drillers logs at site BHW491 show that the medium sand extends to a depth of about 20 ft below land surface and is underlain by fine gray sand and gray marine clay. The fine gray sand, silt, and peat is about 15 ft thick at site BHW491. The gray marine clay, which contains numerous mollusk shells, is at least 15 ft thick and probably represents the lower boundary of the beach aquifer. Glacial sediments underly the marine sand, silt, and clay; the erosional contact between marine and glacial sediments is at a depth of about 25 ft below land surface at site BHW490 and greater than 45 ft below land surface at site BHW491. Beach deposits along the coast of the barrier beach at site BHW495 (fig. 2) consist of coarse brown sand and gravel.

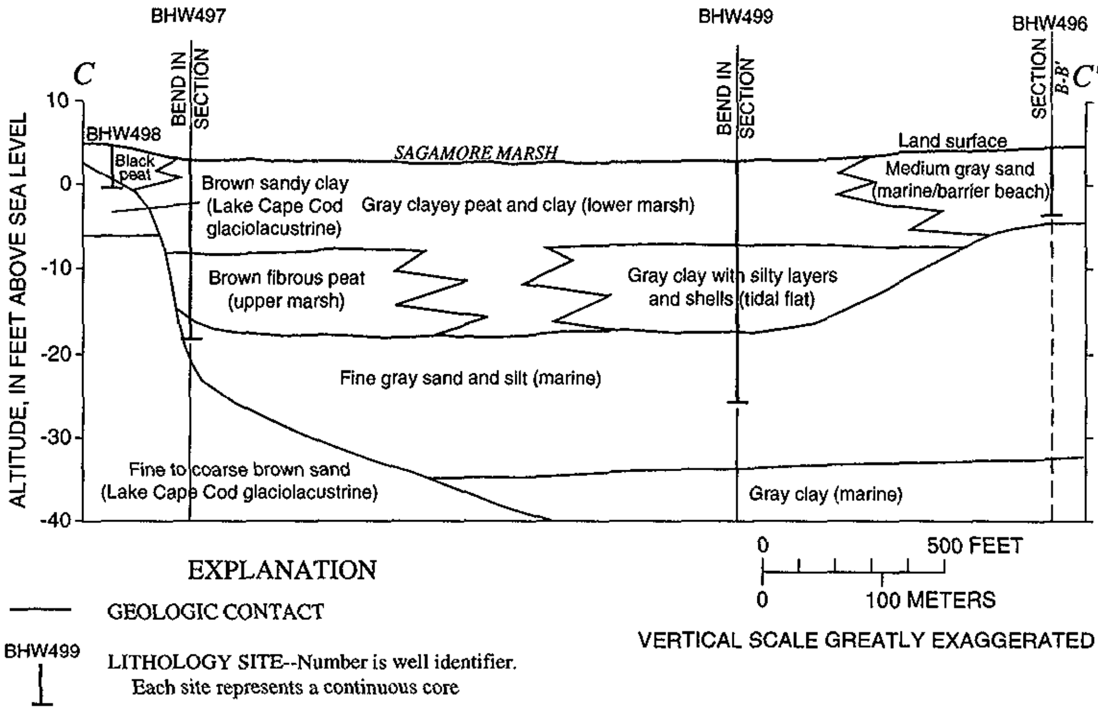
Marsh Sediments

Salt-marsh sediments in Sagamore Marsh range in thickness from 0 ft along the edge of the marsh to more than 20 ft near the center of the marsh (fig. 4*C*). Marsh sediments at site BHW497 include about 12 ft of gray clayey peat and clay underlain by about 8 ft of brown fibrous peat; the total thickness of peat and clay at the site was about 20 ft. Fine gray sand and silt underlies the peat. The brown fibrous peat at the site is consistent with "high-marsh" deposits (Nixon, 1982). Although site BHW497 is close to the present day entrance of the marsh at the Cape Cod Canal, historically the marsh drained to the east into Cape Cod Bay, which indicates this location is analogous to a "high-marsh" environment. Sediments at site BHW498, at the western edge of the marsh consisted of about 4 ft of black and gray peat underlain by brown sandy clay consistent with the glaciolacustrine deposits seen near the surface in section *A-A'*.



***B.* Section *B-B*′.**

Figure 4.—*Continued.*

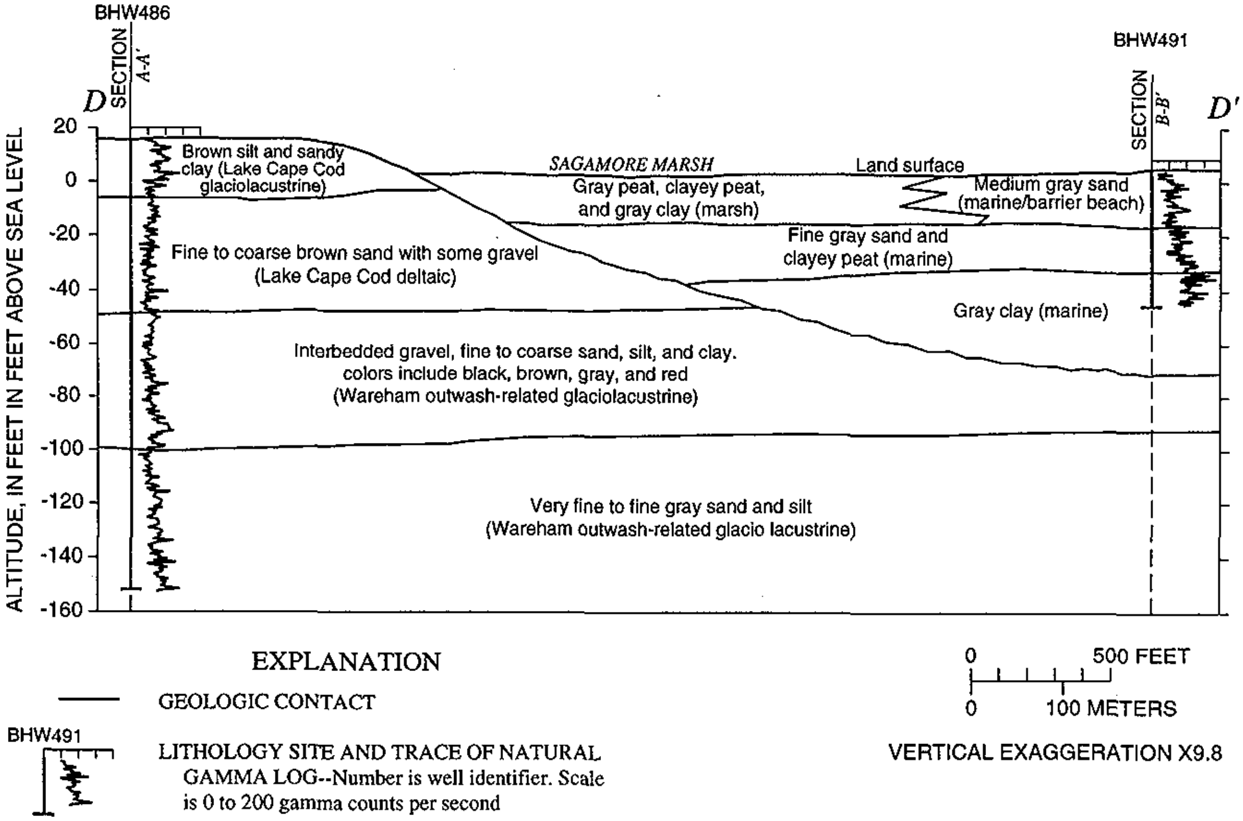


***C.* Section *C-C'*.**

Figure 4.—*Continued.*

The fine-grained marsh sediments (peat and clay) at site BHW497 decrease rapidly in thickness toward the edge of the marsh—from about 20 ft to about 4 ft over a distance of 212 ft. Marsh sediments at site BHW499, which are finer grained than at site BHW497, show about 10 ft of gray clayey peat and clay underlain by about 8 ft of gray marine clay; the total thickness of fine-grained marsh sediments is about 18 ft. The gray clay contains numerous mollusk shells and probably represents a tidal flat depositional environment (Peter Weiskel, U.S. Geological Survey, oral commun., 1995). Site BHW499, which is in the present-day upper marsh, lies closer to the original marsh entrance into Cape Cod Bay and is analogous to a "low-marsh" environment (Teal, 1986). Sediments from site BHW496 show medium gray sand to a depth of at least 8 ft. This sand is underlain by fine sand and silt; the two units are part of the unconfined beach aquifer that underlies the barrier beach between the northeast part of the marsh and Cape Cod Bay. This aquifer, which is about 20 ft thick at site BHW491 (fig. 4*B*), is underlain by marine clay and grades laterally into clayey salt-marsh peat toward the marsh. The stratigraphy shown at site BHW496 is inferred from the stratigraphy at site BHW491 (fig. 4*B*) as determined from geophysical and lithologic logs.

The stratigraphic position of the fine-grained marsh deposits in relation to the glacial and marine stratigraphy in the Sagamore Marsh area is shown in figure 4*D*. The marsh deposits, which consist of peat, clayey peat, and clay, are about 20 ft thick beneath the center of the marsh and are underlain by fine to coarse brown glacial sand and fine gray marine sand and silt. The glacial sand is part of the Lake Cape Cod deltaic hydrogeologic unit at site BHW486, and the fine gray sand is part of the fine sand unit at site BHW491. The two sand units probably are separated by an erosional



***D.* Section *D-D'*.**

Figure 4.—*Continued.*

contact that underlies the marsh and form a single, confined aquifer beneath the marsh. The confining conditions are caused by the overlying marsh sediments, which have low vertical and horizontal hydraulic conductivity. The sand aquifer underlying the northern part of the marsh probably is underlain by gray marine clay. The fine-grained marsh deposits grade laterally to medium gray marine sand toward Cape Cod Bay and are laterally bounded by glaciolacustrine silt and sandy clay along the western edge of the marsh.

Water Table and Potentiometric Surface

Sagamore Marsh is at the downgradient edge of the Plymouth-Carver aquifer system—a large, regional ground-water-flow system. Ground water that enters the flow system as areal recharge generally flows toward the southeast in the area of Sagamore Marsh and discharges to the marsh, Cape Cod Bay, and the Cape Cod Canal (fig. 1). Though most of the regional flow system is unconfined, the low hydraulic conductivity of the fine-grained glaciolacustrine sediments along the western edge of the marsh and of the fine-grained marsh sediments causes confining conditions beneath the marsh; for this reason, the flow system is described as semiconfined near the marsh. Unconfined (or water-table) conditions prevail in the marsh sediments beyond the western and northwestern extent of the confining deposits and along the barrier beach on the northeastern side of the marsh (fig. 5); semiconfined or confined conditions prevail beneath the marsh sediments and along at least the western edge of the marsh (fig. 6).

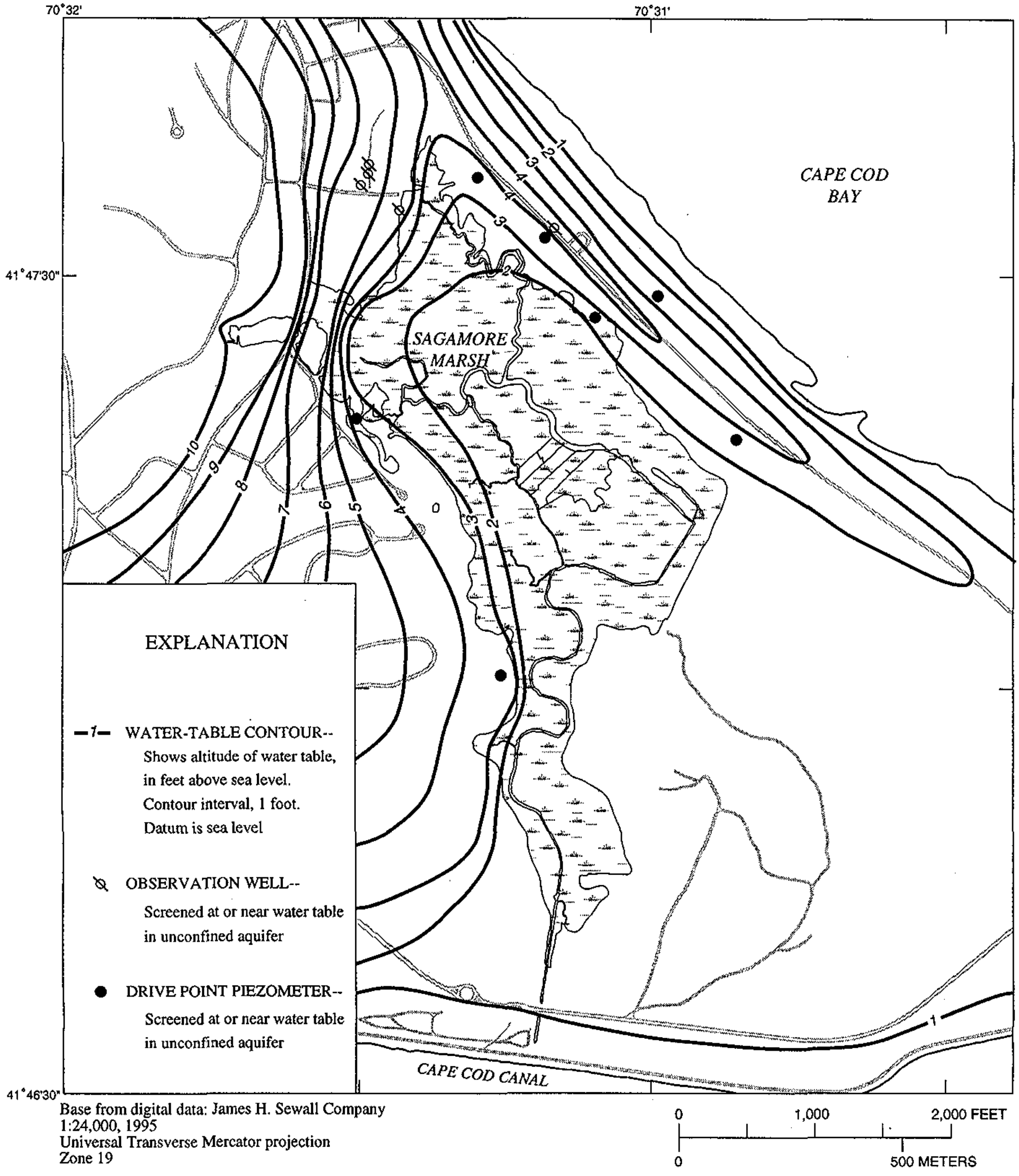


Figure 5. Altitude of water table near Sagamore Marsh, southeastern Massachusetts, June 1995.

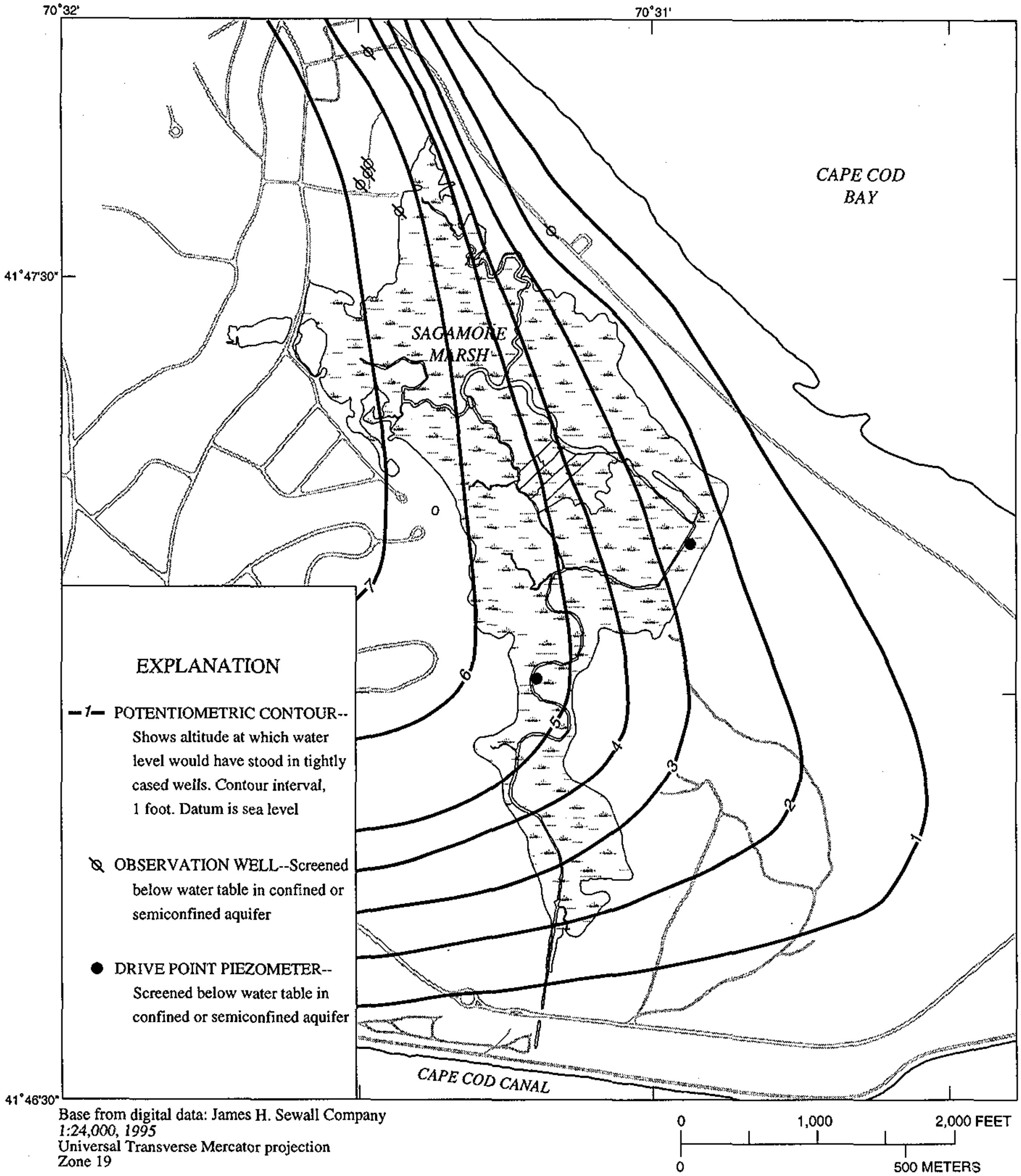


Figure 6. Altitude of potentiometric surface near Sagamore Marsh, southeastern Massachusetts, June 1995.

In June 1995, water-table altitudes near the marsh decreased from about 10 ft along the western edge of the marsh and about 2 ft in the marsh (fig. 5) to sea level near the coast. Maximum water-table altitudes in the fine to medium sand beneath the barrier beach are about 4.5 ft. A water-table mound appears to exist beneath the barrier beach; ground-water flow on the eastern side of the barrier beach is toward Cape Cod Bay and ground-water flow on the western side of the barrier beach is toward the marsh. The water table along the marsh side of the barrier beach was close to land surface during June 1995; depth to the water table from land surface ranged from 1.73 ft (site BHW496) to 0.81 ft (site BHW493). Depth to the water table from land surface along the western boundary of the marsh in June 1995 ranged from 9.98 ft at site BHW486 to 0.82 ft at site BHW498. The direction of water-table gradients along the western, northwestern, and northeastern boundaries of the marsh are toward the marsh, indicating that shallow ground water discharges to the marsh from these directions (fig. 5).

Altitude of the potentiometric surface in the confined or semiconfined aquifer in June 1995 (fig. 6) ranged from about 10 ft above sea level along the western edge of the marsh to near sea level at the coast; hydraulic head may be above sea level and ground water may discharge beneath Cape Cod Bay for some distance out from the shoreline. The sand aquifer that underlies the marsh is confined by the fine-grained marsh sediments and upward head gradients beneath the marsh were large. In June 1995, the confined water level in the lower marsh, site BHW497, was 2.62 ft above land surface and the confined water level in the upper marsh, site BHW499, was about 0.1 ft below land surface. The water table at both of these locations was about 1 ft below land surface at the time of measurement. The upward gradient between the confined aquifer and the marsh surface suggests that there is little if any downward flow of salty water from the marsh to the underlying sand aquifer.

Ground water discharges to springs and seeps near and in the marsh. Springs and seeps occur along the western edge of the marsh (Matthew Walsh, U.S. Army Corps of Engineers, oral commun., 1995); a spring was observed during the investigation near the public-supply well (site BHW013). Ground-water seeps also were observed along the northeastern edge of the marsh. In addition, ground water discharges to a small pond along the western edge of the marsh; freshwater outflow from the pond that was measured at about 0.1 ft^3/s in June 1995 forms a small freshwater tributary to the marsh. Ground water in the confined system beneath the marsh flows to the southeast and likely discharges into Cape Cod Bay and the Cape Cod Canal.

Tidal Effects on Ground-Water Levels

Tidal fluctuations in Cape Cod Bay, Cape Cod Canal, and in tidal channels in Sagamore Marsh affect ground-water levels in the unconfined and confined ground-water systems; tidal ranges in Cape Cod Bay and the Cape Cod Canal were on the order of 9 and 6 ft, respectively, during the study. The tidal cycle in the tidal channels is a function of the tidal cycle in Cape Cod Canal, which had a range of about 6 ft during the study period. The mean range in tidal stage measured in stilling wells in the upper marsh (site BHW499) and lower marsh (site BHW497) were 1.30 and 1.35 ft, respectively, from June 29 to July 18, 1995 (fig. 7). A third stilling well at site BHW501 in a small freshwater tributary at the western edge of the marsh also was tidally influenced and had a range of mean tidal stage of 0.65 ft over the same period. The mean baseflow altitude of the stream at site BHW501 was about 1.9 ft above sea level; during high tide, the stage increased to within 0.1 ft of high-tide stages in the lower marsh. High tide in the upper marsh (site BHW499) and at the marsh edge (site BHW501) occurred after high tide in the lower marsh (site BHW497) and were offset by +22.5 and +47.4 minutes, respectively; a positive offset indicates a later high and low tide than at the lower marsh site. The monthly or lunar tidal cycle at site BHW497 showed a range in mid-tidal stages of 0.45 ft between the neap tide (July 7, 1995) and the spring (full moon) tide (July 15, 1995).

Tidal fluctuations in the water table were measured at two sites along the northeastern edge of the marsh (sites BHW492 and BHW496) and at one site along the beach (site BHW495) (fig. 7*B*). The tidal cycle at site BHW495, which is about 100 ft from Cape Cod Bay, is a function of the tidal cycle in the bay. The range in mid-tidal stages between the neap tide (July 7, 1995) and the spring tide (July 15, 1995) at site BHW495 was 1.05 ft, which was significantly higher than the range in the marsh tidal channels (fig. 7*B*). The range of mean daily tidal stage at site

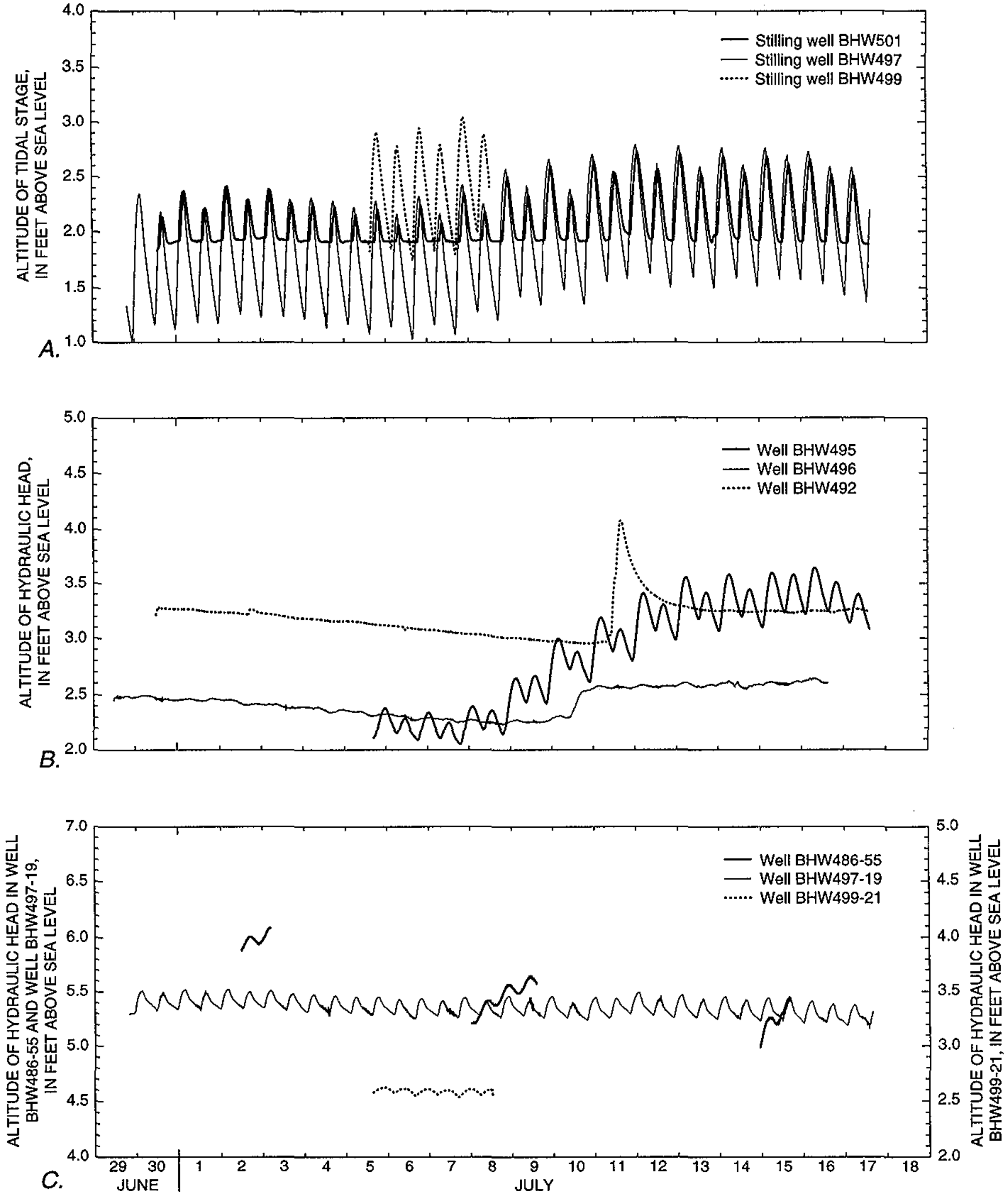


Figure 7. Tidal fluctuations in and around Sagamore Marsh at (*A*) three points in the main tidal channel, (*B*) three points in the unconfined aquifer, and (*C*) three points in the confined aquifer, southeastern Massachusetts, June 29 to July 18, 1995.

BHW495 was 0.5 ft and the range of mean daily tidal stage in Cape Cod Bay was about 9 ft. The large attenuation of the tidal cycle between Cape Cod Bay and site BHW495 probably results from the relatively low diffusivity of the beach deposits—aquifer diffusivity is defined as the ratio of transmissivity (*T*) to storativity or specific yield (*S* or *Sy*). There was no discernible tidal cycle at site BHW492; this site is about 125 ft from the main tidal channel in the marsh and about 300 ft from Cape Cod Bay. The range of mean tidal stage at site BHW496 was about 0.03 ft; the site is about 690 ft from the upper-marsh tidal channel and about 560 ft from Cape Cod Bay. Ground-water level rises at sites BHW492 and BHW496 from July 10-12, 1995, are due to precipitation events (fig. 7*B*).

The tidal cycle at site BHW496 was offset from the tidal cycle in the ground water at site BHW499 by about +317.5 minutes and was offset from the tidal cycle in ground water at the beach (site BHW495) by only +72.5 minutes suggesting that the tidal cycle was more in phase with the tidal pulse originating from Cape Cod Bay than the tidal pulse originating from Sagamore Marsh. Data from the June 1995 aquifer test showed no discernible tidal influence in the water table at site BHW486 near the northwestern boundary of the marsh. The effects of the tidal-channel stage fluctuations on ground-water levels in the unconfined (water-table) aquifer along the barrier beach are negligible suggesting that Cape Cod Bay probably has more affect on ground-water levels in that area than does Sagamore Marsh.

Tidal cycles and fluctuations were measured at two sites in the confined aquifer beneath the marsh (sites BHW497 and BHW499). The mean range of tidal fluctuations in ground water at site BHW497 was 0.15 ft. The range of tidal fluctuations in the tidal channel was about 1.35 ft. The range of tidal fluctuations in ground water was almost one-tenth of those in the tidal channel and probably is due to the low diffusivity of the marsh sediments. The tidal cycle in ground water was offset from the tidal cycle in the channel by about -20.0 minutes—high tide in the ground water occurred about 20 minutes before the high tide in the channel. The presence of a more conductive hydraulic connection between the tidal channel and the aquifer near the present day entrance to the marsh in combination with confined conditions may be the cause of the earlier high tide in ground water. The tidal channel at a downgradient location, which would have an earlier high tide than site BHW497, probably would be underlain by glacial sediments that are coarser grained than the marsh sediments. The earlier high tide in ground water also may indicate that tidal fluctuations in Cape Cod Canal are transmitted more rapidly through the confined glacial aquifer than through the tidal channel and that the ground-water tidal cycle at site BHW497 is more in phase with tidal fluctuations in the canal.

The mean range of tidal fluctuations in ground water at site BHW499 was 0.07 ft, which was about one-twentieth of the range of tidal fluctuations in the tidal channel, indicating that the tidal pulse in ground water at the upper marsh site was more attenuated than the tidal pulse in ground water at the lower marsh site. This may be a function of the different lithologies at the two sites. The marsh sediments at the upper marsh site, which consist of clayey peat and clay, were finer grained than the clayey peat and fibrous peat at the lower marsh site; the lithology indicates that marsh sediments at the upper site probably are less hydraulically connected to the underlying aquifer. The tidal cycle in ground water at site BHW499 was offset from the tidal cycle in the tidal channel by about +123.5 minutes.

The mean range of tidal fluctuations in ground water at site BHW486 at the northwestern edge of the marsh and near the public-supply well was 0.17 ft. The tidal cycle at site BHW486 was offset from the tidal cycle in the channel at site BHW501 by about +69.8 minutes and was offset from the tidal cycle in the channel at site BHW495, adjacent to Cape Cod Bay by about -175.2 minutes. The tidal cycle at site BHW486 is more in phase with tidal cycles in the marsh tidal channels suggesting that the tidal pulse in the confined aquifer originates in the marsh. Data collected during an aquifer test in June 1995 (fig. 9*A*) showed no discernible tidal cycle in the water table at site BHW486-15. Tidal cycles were in phase with the tidal cycle at site BHW486 in the semiconfined wells at sites BHW487, BHW488, and BHW489. The tidal range was largest at site BHW489, which is close to the northeastern edge of the marsh.

Tidal fluctuations at sites BHW487, BHW488, and BHW489 in the confined aquifer are small—less than 0.2 ft. Tidal pulses in the confined aquifer at these sites probably are affected more by tidal pulses originating in the marsh than by tidal pulses originating from Cape Cod Bay.

The use of tidal lags to identify the origin of the tidal fluctuations in ground-water levels can be complicated by extremely long tidal lags, particularly for sites at large distances from the tidal channels and from Cape Cod Bay. In the case of site BHW486, the offset of -175.2 minutes from the drive point near Cape Cod Bay (site BHW495) indicates that the pulse is more in phase with tidal pulses from the tidal channels in the marsh, however, the tidal pulse could originate from Cape Cod Bay and the offset could represent a +579.8 minute lag from the previous tidal pulse in the bay. Large tidal pulse attenuation and large time lags between Cape Cod Bay and site BHW495 may indicate that the beach sediments have a low aquifer diffusivity. The presence of peat interbeds beneath the barrier beach may limit the effective thickness of the aquifer and, therefore, the effective transmissivity of the beach aquifer. The low effective transmissivity and the high specific yield of the beach sediments, which consist of sand and gravel, would cause a low aquifer diffusivity and could result in large time lags in tidal pulses. The presence of a barrier-beach, water-table mound with altitudes of greater than 4 ft above sea level also may indicate that the vertical diffusivity of the beach deposits is low.

Response of Flow System to Pumping

An aquifer test was done near the northwest edge of the marsh at site BHW013 during June 1995. The existing public-supply well at the site was pumped continuously for 5 days at an average rate of 473 gal/min and drawdowns were measured in 10 nearby observation wells. The public-supply well is screened from 32.71 to 40.71 ft below sea level in the fine to coarse brown glacial sand (Lake Cape Cod deltaic sediments) shown in figure 4*A*. After 5 days of pumping, drawdown measured in the pumped well was 17.5 ft. Drawdown was measured in observation wells screened at the same depth as the supply well.

Supply well No.	Distance of observation well from supply well (feet)	Measured drawdown in observation well (feet)
BHW486	100	4.92
BHW487	183	4.05
BHW488	280	3.52
BHW489	491	3.18
BHW490	725	1.67
BHW491	1,450	.37

Drawdown data plotted against time for the four closest observation wells (BHW486-55, BHW487-52, BHW488-53, and BHW489-49) show S-shaped curves that are characteristic of the response of an unconfined aquifer to pumping (fig. 8), as do the drawdown data from observation well BHW486-15 that is screened at the water table (fig. 9). Late-time data also indicate that ground-water levels were affected by tidal cycles in either Cape Cod Bay or the marsh channels, as indicated by the sinusoidal fluctuations of drawdown at times greater than about 400 minutes.

At the start of the aquifer test, the water table near the pumped well was in the glaciolacustrine silt and clay hydrogeologic unit. Shortly after pumping began, the water table measured at the pumped well (BHW013) declined below this silt and clay unit, which is shown in hydrogeologic sections in figures 3, 4*A*, and 9. At well BHW486-15, at a distance of 100 ft from the pumped well, the water table declined below the bottom of the screened interval of the observation well (which is 1.8 ft above the contact of the glaciolacustrine and glacial sand units) after nearly 2 days of pumping; it is uncertain whether or not the water table declined below the bottom of the glaciolacustrine unit at this site during the course of the aquifer test. The glaciolacustrine unit probably contributes to the confining conditions that exist near the marsh for nonpumping conditions. During the course of the aquifer test, the water table was drawn down below the confining unit and the flow system became completely unconfined in the immediate vicinity of the pumped well. The distance from the pumped well at which strictly unconfined flow conditions prevail is unknown. Drawdown was not measurable during the course of the aquifer test in well BHW486-175, which is screened in the bottom glaciolacustrine hydrogeologic unit at a depth of 169 to 171 ft below land surface, indicating that the depth of influence of the pumped well was less than 169 ft.

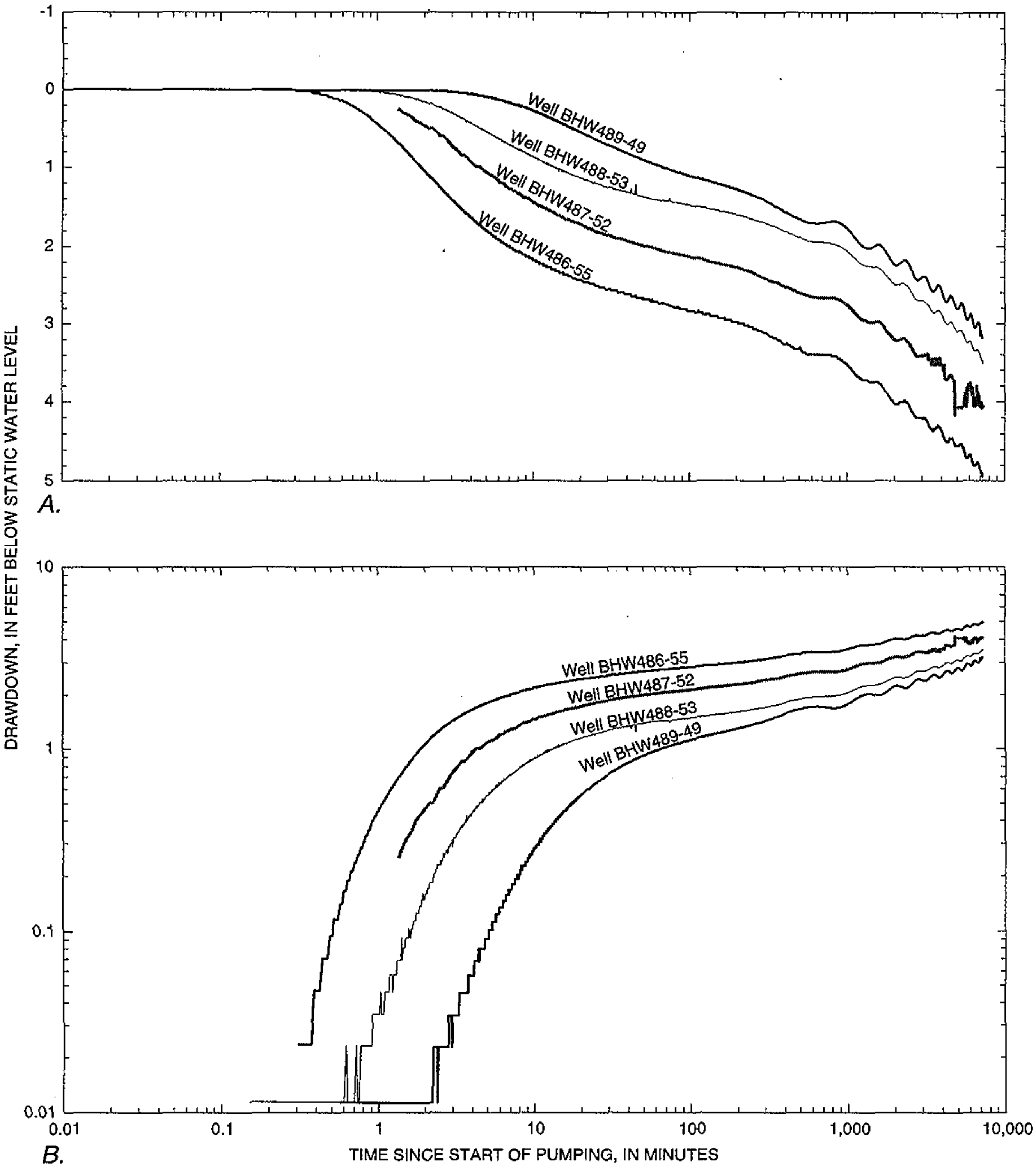


Figure 8. Time-drawdown curves for wells BHW486-55, BHW487-52, BHW488-53, and BHW489-49 near Sagamore Marsh, southeastern Massachusetts, during June 1995 aquifer test using (*A*) a semilog scale and (*B*) a log-log scale.

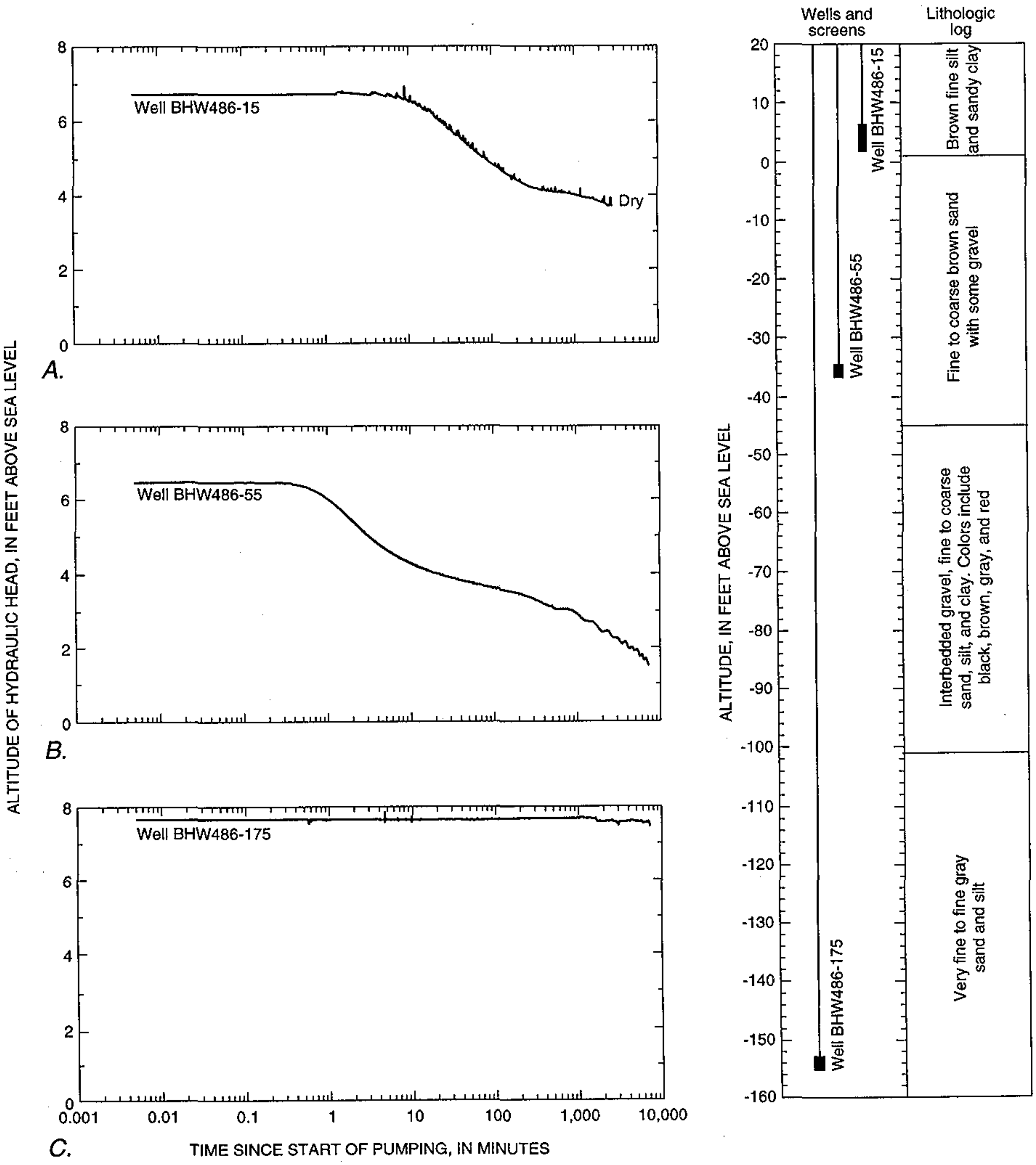


Figure 9. Drawdown in (*A*) water table, (*B*) intermediate confined aquifer, and (*C*) deep aquifer during aquifer test and lithologic log of site BHW486 near Sagamore Marsh, southeastern Massachusetts, June 1995.

Drawdown was 0.37 ft at the water-table well at site BHW491 on the barrier beach at the end of the 5 days of pumping. Site BHW491 is about 1,450 ft from the supply well and is separated from the supply well by the northwestern part of the marsh. These results suggest that the fine to coarse brown sand (Lake Cape Cod deltaic) sediments along the northwestern edge of the marsh are hydraulically connected to the fine gray marine sand underlying the barrier beach; this hydraulic connection, which is illustrated on the hydrogeologic section *D-D'* (fig. 4*D*), is through the sandy sediments underlying the marsh.

Measurements of specific conductance of water discharged at the pumped well and at observation well BHW490, about 725 ft from the pumped well (fig. 2), were made at 4-hour intervals during the aquifer test to monitor the possible saltwater intrusion from Cape Cod Bay into the flow system or the possible upconing of saltwater from deeper intervals of the aquifer into the pumped well. These measurements indicated no significant change and no discernible trend in the specific conductance measurements of ground water at the pumped or observation wells. Specific conductances at the pumped well ranged from 120 to 160 μS/cm and averaged about 150 μS/cm. Electromagnetic induction logs also were collected at sites BHW486 and BHW490 before and after the aquifer test to determine if any change in the conductivity of the aquifer had occurred during the aquifer test; an increase in the conductivity of the aquifer at these deep observation wells would indicate saltwater intrusion or upconing. No changes in the electromagnetic induction logs from pre-pumping conditions were observed. It cannot be concluded from these results, however, that there was no response of the freshwater-saltwater interface to pumping anywhere in the system during the aquifer test; vertical ground-water movement would be slow in fine-grained sediment. The results simply indicate that there were no measurable changes at the observation wells during the aquifer test.

Hydraulic Properties of Hydrogeologic Units

Hydraulic properties of the hydrogeologic units near Sagamore Marsh have been estimated from data collected as part of this investigation. These properties include the aquifer transmissivity, ratio of vertical to horizontal hydraulic conductivity, storage properties of the glacial sand aquifer, and the hydraulic diffusivity of the marsh sediments. Hydraulic properties of the hydrogeologic units are needed for a quantitative analysis of the ground-water-flow system.

Hydraulic Properties of Regionally Significant Hydrogeologic Units Near Sagamore Marsh

Results of the 5-day aquifer test at the public-supply well (BHW013) were analyzed by use of two techniques developed by Neuman (1972, 1974, and 1975). Both methods are based on the assumption that water is withdrawn from an unconfined, homogeneous, and anisotropic aquifer that is of infinite lateral extent and bounded at depth by an impermeable horizontal barrier. Neuman's methods were selected because the results of the 5-day aquifer test indicate unconfined conditions during at least part of the test. The difference between the two methods is that the first assumes that the pumped and observation wells fully penetrate the aquifer, whereas the second assumes that the pumped and observation wells partially penetrate the aquifer. The major limitation of Neuman's methods, as with most analytical methods, is that it is necessary to assume that the aquifer is homogeneous, which is not completely consistent with field data collected at the site. However, the assumption of homogeneity is considered to be sufficient for the intended use of the results, which is a first-level determination of the hydraulic properties of the aquifer near the well.

The first analysis assumes that both the pumped and observation wells fully penetrate the aquifer (Neuman, 1975). This is a common assumption made in aquifer-test analyses and simplifies the analysis by allowing the determination of transmissivity from a semilogarithmic plot of time versus measured drawdown at each of the observation wells (fig. 10).

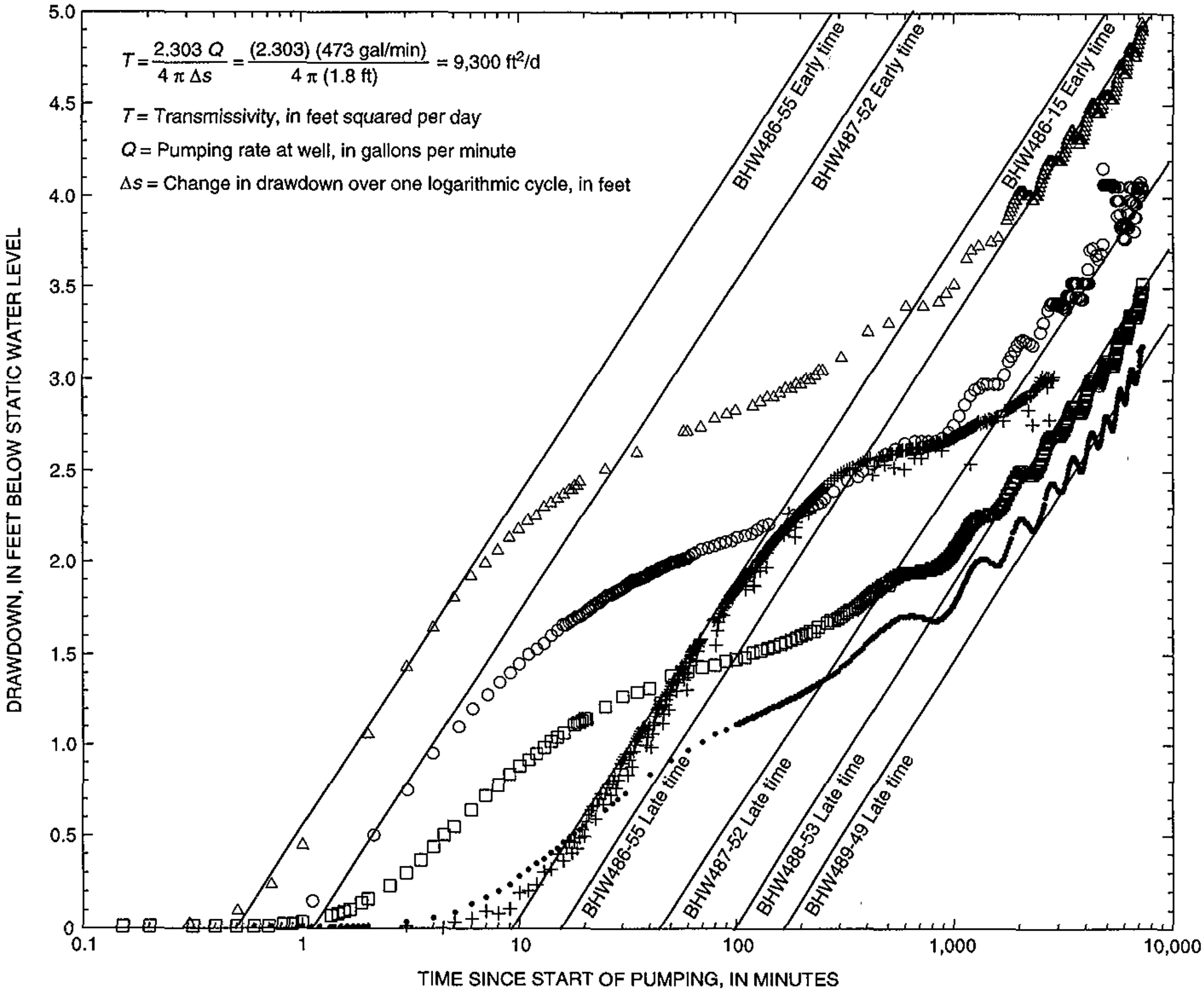


Figure 10. Measured drawdown at selected wells and determination of transmissivity near Sagamore Marsh, southeastern Massachusetts.

As shown in figure 10, parallel lines were drawn through early- and late-time intervals of most of the time-drawdown curves. The slope of each line was the same for early- and late-time intervals, as it should be for conditions of unconfined flow (Neuman, 1975, p. 332) and a homogeneous flow system. A transmissivity of 9,300 ft^2/d was determined from the slope of the lines. The saturated thickness of that part of the aquifer that is assumed to supply water to the well is 51.3 ft, which is based on the thickness of the aquifer from the water table to the bottom of the glacial sand hydrogeologic unit (Lake Cape Cod deltaic sediments; fig. 3). Therefore, the calculated transmissivity of 9,300 ft^2/d corresponds to a horizontal hydraulic conductivity of 181 ft/d.

Storage coefficient and specific yield also were determined from the semilogarithmic analysis, following Neuman (1975). Early-time data were used to determine storage coefficient and late-time data were used to determine specific yield (Neuman, 1975). Calculated storage coefficient of the aquifer ranged from 4.4×10^{-4} (well BHW486-55) to 5.0×10^{-4} (well BHW487-52); specific yield ranged from 0.01 (well BHW489-49) to 0.02 (wells BHW488-53, BHW487-52, and BHW486-55).

The second method assumes that the pumped and observation wells partially penetrate the aquifer, which is consistent with the conditions at site BHW013. The second method was applied to determine the effect of the assumption of fully penetrating pumped and observation wells on the calculated transmissivity. Theoretical time-drawdown curves (also called type curves) were generated using the computer program WTAQ1 (Moench, 1993), which is based on the theory of Neuman (1972 and 1974). Dimensionless variables for each pumped well-observation well pair are required to generate individual theoretical curves; these data are shown in table 2. An initial, prepumping saturated thickness of the aquifer of 51.3 ft was used in calculating the dimensionless variables shown in table 2. No single (or universal) set of hydraulic property values could be found in which the measured drawdown data and theoretical curves overlapped simultaneously for all five time-drawdown curves, probably because of the heterogeneity of the aquifer deposits near the pumped well. However, good matches could be found when individual drawdown curves were matched to theoretical curves separately. The best match between measured time-drawdown data and the type curves at well BHW486-55 was obtained for a value of transmissivity (T) of 10,900 ft^2/d, a ratio of vertical to horizontal hydraulic conductivity (K_Z/K_H) of 1:44, a ratio of storage coefficient to specific yield (σ) of 0.09, a storage coefficient (S) of 0.0026 and a specific yield (S_y) of 0.03 (fig. 11). Two theoretical curves determined for transmissivity equal to 75 and 125 percent of the value determined from the best match to the measured data also are shown in figure 11. The low values of K_Z/K_H and of S_y determined from the analysis probably result from the presence of the glaciolacustrine silt and clay hydrogeologic unit at the top of the stratigraphic column. The water table at the test site was in this unit at the start of the aquifer test and moved downward through the unit during the test. A horizontal hydraulic conductivity of the glacial sand hydrogeologic unit of 213 ft/d is calculated from the estimated transmissivity on the basis of an assumed saturated thickness of the aquifer of 51.3 ft. The transmissivity and hydraulic conductivity calculated for this observation well are higher than, but very similar to those calculated in the previous analysis, which suggests that partial penetration of the pumped and observation wells is not an important variable in the analysis of hydraulic properties at the site. Transmissivities calculated using the two methods are consistent with those determined for similar deposits of Cape Cod by Barlow and Hess (1993), Barlow (1994), and Masterson and Barlow (1994).

Table 2. Data required for each pumped well and observation well pair for the analysis of hydraulic properties near well BHW013, near Sagamore Marsh, southeastern Massachusetts

[**Site identifier:** Location of sites shown in figure 2. **Dimensionless variables:** l_D is from the initial water table to the bottom of the screened interval of the pumped well to the initial saturated thickness. d_D is from the initial water table to the top of the screened interval of the pumped well to the initial saturated thickness. z_{D1} is from the bottom of the aquifer to the bottom of the screened interval of the observation well to the initial saturated thickness. z_{D2} is from bottom of the aquifer to the top of the screened interval of the observation well to the initial saturated thickness. Dimensionless = foot per foot. ft, foot]

Well identifier	Radial distance from pumped well (ft)	Dimensionless variable			
		l_D	d_D	z_{D1}	z_{D2}
BHW486-15	100	0.92	0.76	0.95	1.00
BHW486-55	100	.92	.76	.19	.23
BHW487-52	183	.92	.76	.21	.25
BHW488-53	280	.92	.76	.24	.27
BHW489-49	491	.92	.76	.12	.15

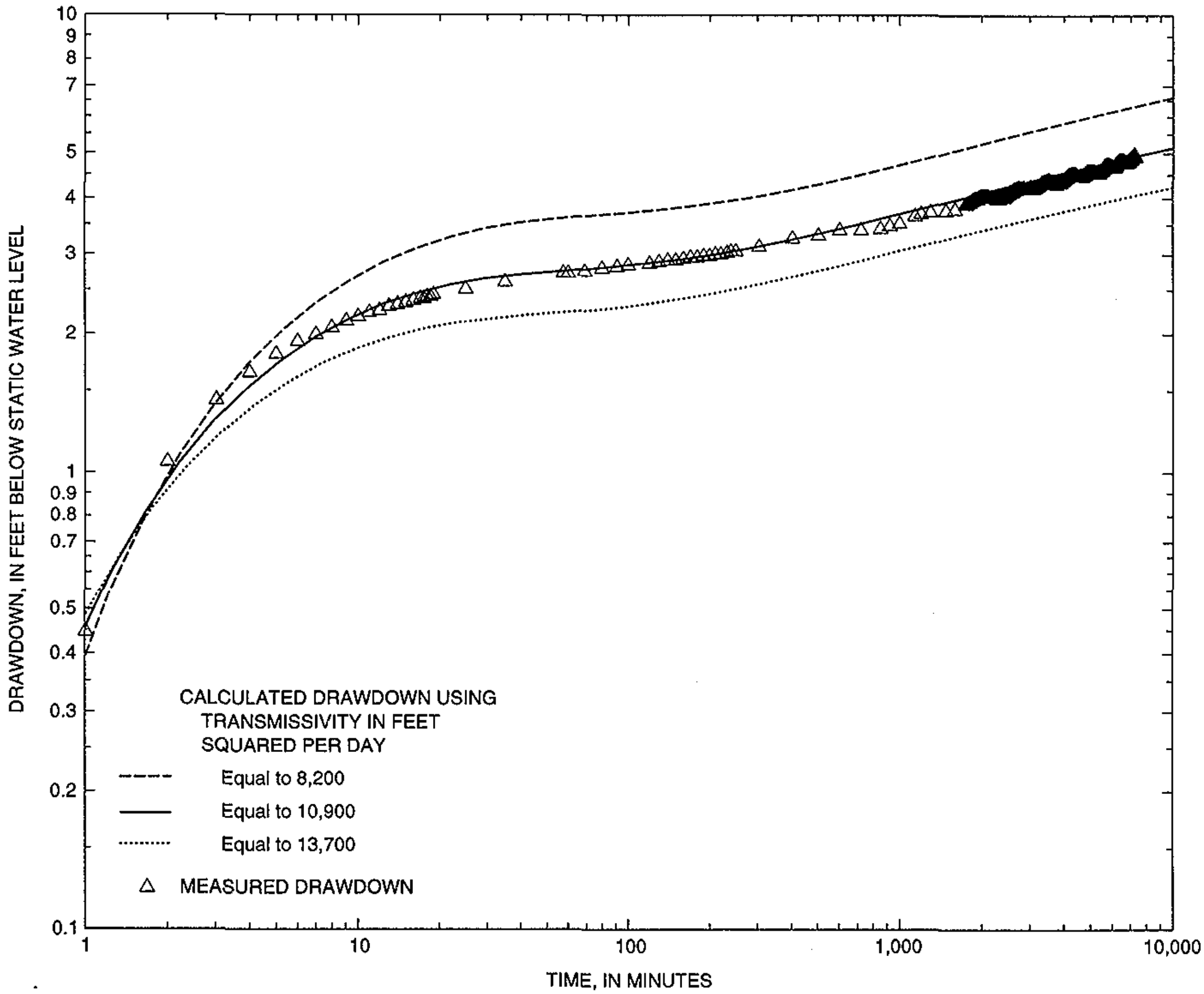


Figure 11. Measured and calculated drawdown at well BHW486-55 near Sagamore Marsh, southeastern Massachusetts.

Hydraulic Properties of Marsh Sediments

The hydraulic conductivity of the marsh sediments varies with lithology. Knott and others (1987) reported that the hydraulic conductivity of most fibrous salt-marsh peat ranges from 0.03 to 280 ft/d, with a median of about 3 ft/d; the upper part of this range is similar to values reported for medium sand (Freeze and Cherry, p. 29, 1979). Hydraulic conductivities reported for marine clay are much lower and range from 10^{-7} to 10^{-4} ft/d (Freeze and Cherry, 1979). Clayey peat, which is observed at both marsh coring sites, probably has an intermediate hydraulic conductivity that is closer to the hydraulic conductivity of marine clay. Marsh sediments from site BHW497 consisted primarily of gray clayey peat underlain by brown fibrous peat. These sediments probably have a higher hydraulic conductivity than marsh sediments at site BHW499, which consisted of clayey peat underlain by gray clay. Although ranges in tidal stage in the tidal channel at sites BHW497 (lower marsh) and BHW499 (upper marsh) were similar, ranges of tidally influenced ground-water-level fluctuations at site BHW497 (0.15 ft) were significantly greater than at site BHW499 (0.07 ft) suggesting that sediments at the lower marsh site are more conductive than those at the upper marsh site.

Ferris (1963) developed an analytical method to determine the diffusivity (α) of an aquifer that is based on the ratio of cyclic water-level fluctuations in tidal water bodies to the corresponding cyclic water levels in an adjacent aquifer. This ratio is called the tidal-range ratio. As stated previously, the diffusivity of an aquifer is defined as the transmissivity (T) divided by storage coefficient (S). The method developed by Ferris assumes that ground-water flow near the tidal channel is one dimensional; that is, that the hydraulic pulse propagated at the channel moves in one direction outward from the channel. The equation relating the tidal-range ratio to diffusivity is:

$$\log\frac{Rgw}{Rsw} = -0.77x\sqrt{\frac{1}{\alpha t}}\ , \tag{1}$$

where Rgw and Rsw are the tidally influenced ranges in ground-water and surface-water levels, respectively, in feet; x is the distance of the observation well from the tidal channel, in feet; α is aquifer diffusivity, in square feet per day; and t is the period of the tidal cycle, in days.

Equation 1 was used to estimate the diffusivity of the marsh sediments at sites BHW497 and BHW499. In using equation 1, which is a one-dimensional analysis, the assumption was made that the tidal pulse propagated vertically from the tidal channel through the marsh sediments and that the attenuation observed at the contact between the fine sand aquifer and the marsh sediments was a function of the diffusivity of the marsh sediments. Tidal cycles at both sites for July 5-8, 1995 are shown in figure 12. In the lower marsh (site BHW497), ranges of tidally influenced ground-water and surface-water levels were 0.17 and 1.16 ft, respectively. The vertical distance from the bottom of the tidal channel to the observation well was 15 ft and the period of the tidal cycle was 0.51 days. Using equation 1, a diffusivity of 380 ft^2/d was calculated for sediments at the site. The hydraulic conductivity of the marsh sediments at site BHW497 is 2.5×10^{-3} ft/d assuming a storage coefficient of 0.0001 for the marsh sediments—determined from published values of aquifer compressibility (Freeze and Cherry, p. 5, 1979)—and an effective thickness of 15 ft, which is the assumed width of the tidal channel. In the upper marsh (site BHW499), ranges of tidally influenced ground-water and surface-water levels were 0.06 and 1.06 ft, respectively. The vertical distance from the bottom of the tidal channel to the observation well and the period of the tidal cycle were the same as for the lower marsh site—15 ft and 0.51 days, respectively. The value of diffusivity at the upper marsh site, as determined from equation 1, was 170 ft^2/d. Assuming a storage coefficient of 0.0001 and an effective thickness of 10 ft, which is the assumed width of the tidal channel, the hydraulic conductivity of the marsh sediments at site BHW499 (upper marsh) is 1.7×10^{-3} ft/d. The lower conductivity seen at the upper marsh site (site BHW499) is due to the presence of finer grained sediments than at site BHW497. Estimated hydraulic conductivities at both sites were intermediate between the reported values for fibrous peat and marine clay, but are closer to values reported for marine clay.

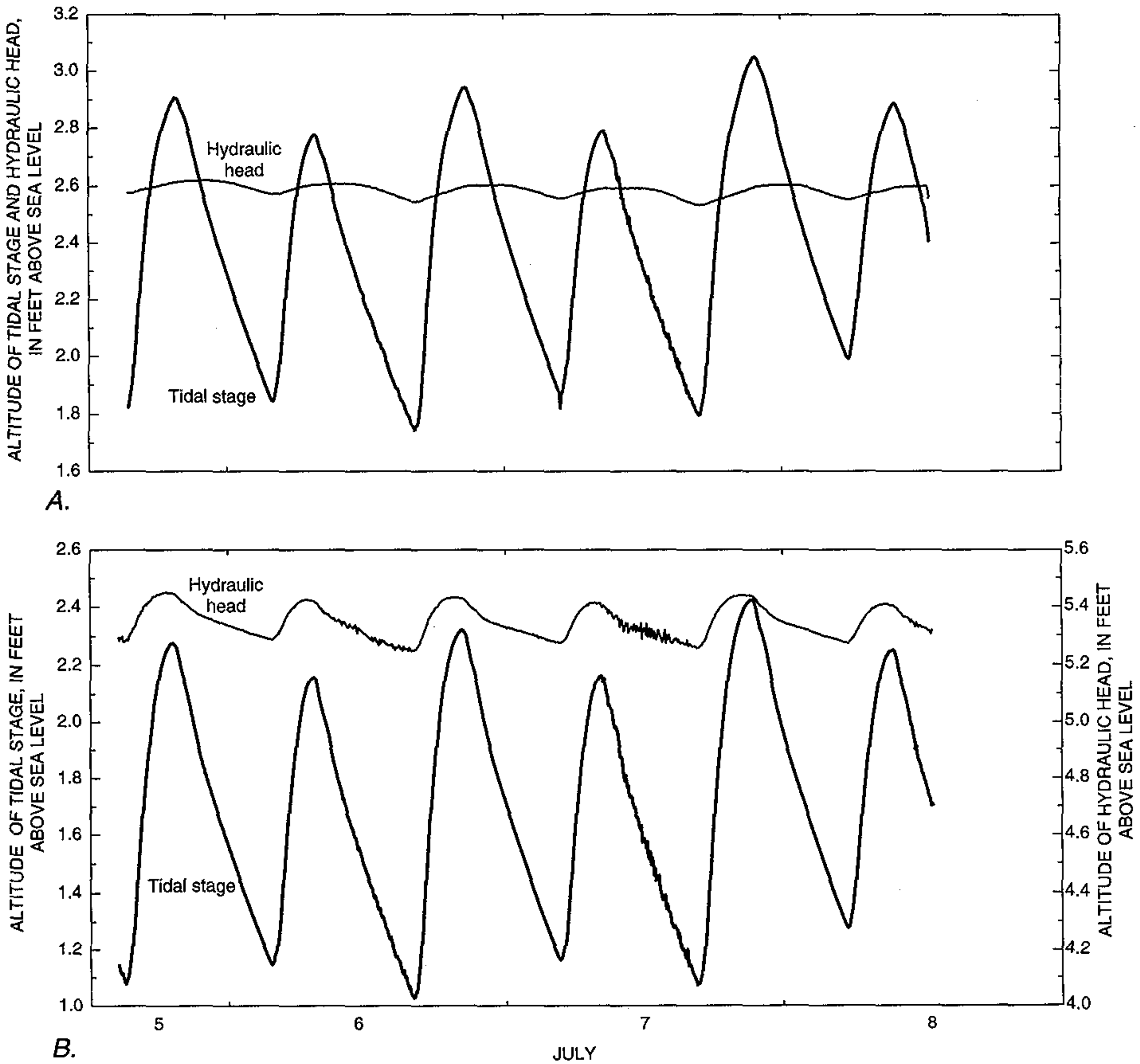


Figure 12. Tidal-stage fluctuations in the main tidal channel and hydraulic head fluctuations in adjacent wells at two locations in Sagamore Marsh, southeastern Massachusetts, July 5-8, 1995.

ANALYSIS OF GROUND-WATER-FLOW SYSTEM

Analytical- and numerical-modeling methods were used in the analysis of the ground-water-flow system near Sagamore Marsh. Specifically, the analysis addresses (1) how ground-water levels in and near the marsh might be affected by increases in tidal-channel stages following increases in the amount of salt water allowed to flow into the marsh, and (2) how the contributing area and source of water to the public-supply well (BHW013) might be affected by the higher tidal stages.

Analytical-Modeling Analysis of the Response of the Ground-Water-Flow System to Increased Tidal Stage

The relation between tidal-pulse attenuation and the diffusivity of marsh and aquifer sediments, discussed previously, was used to predict the effect of higher tidal stages on ground-water levels near the marsh. Projected high tidal stages in the lower and upper parts of the marsh were determined by the U.S. Army Corps of Engineers using a surface-water-flow model; rises in high tidal stages at sites BHW497 (lower marsh) and BHW499 (upper marsh) are anticipated to be less than +1.0 and +0.6 ft, respectively (Matthew Walsh, U.S. Army Corps of Engineers, oral commun., 1995). These anticipated rises in tidal stage are based on an assumed installation of two 10×20 foot culverts at the marsh entrance to the Cape Cod Canal; the actual size of the culvert that is being proposed is only 6×12 ft, which would result in a smaller amount of saltwater flow into the marsh and lower tidal-stage rises than those evaluated here. Tidal pulses originating from the tidal channels could be propagated through the marsh sediments—the water table occurs within the marsh sediments—or through the underlying fine sand aquifer.

Equation 1 was used to calculate the theoretical maximum distance from the tidal channel at which the tidally influenced ranges in ground-water and surface-water levels in the marsh sediments (*Rgw*) would be less than 0.01 ft. The theoretical distance for current and predicted tidal stages was determined using the calculated value of marsh-sediment diffusivity at the two marsh sites, and substituting present and predicted values for the tidally influenced ranges in ground-water and surface-water levels in the channel (*Rsw*). The analysis assumes that marsh sediments are nearly isotropic (Knott and others, 1987) and that the calculated diffusivities, which assumed vertical propagation of the tidal pulse, are the same in the horizontal direction. Based on current (1995) conditions, the estimated maximum distance at which the range of tidal fluctuations in the aquifer exceed 0.01 ft is 37.1 ft at the lower marsh site (BHW947) and 24.3 ft at the upper marsh site (BHW499). The maximum distances of tidal effects exceeding 0.01 ft after tidal stages (*Rsw*) increased to the levels predicted by the U.S. Army Corps of Engineers—2.16 at site BHW497 (lower marsh) and 1.66 at site BHW499 (upper marsh)—were 42.0 and 26.7 ft, respectively.

Equation 1 also was used to determine theoretical distances of tidal pulse propagation in the underlying fine sand aquifer. The hydraulic conductivity of the fine sand and silt underlying the marsh was estimated to be about 30 ft/d; this estimate was based on cores collected in the marsh and published values of hydraulic conductivity from a similar hydrogeologic environment (Masterson and Barlow, 1994). An assumed storativity of 0.0026 from the 5-day aquifer test was used to determine aquifer diffusivities. An aquifer thickness of 15 ft was determined from lithologic data; owing to the probable high anisotropy of the fine sand and silt, the effective aquifer thickness may be significantly smaller and the use of 20 ft as an aquifer thickness probably would overestimate tidal-pulse propagation distances. The tidal pulses measured in the aquifer beneath and adjacent to the tidal channels, which was 0.17 at site BHW497 (lower marsh) and 0.06 at site BHW499 (upper marsh), were used as the initial tidal pulses (*Rgw*) in equation 1. The initial tidal pulses used in estimating propagation distances after tidal stages increase was determined by multiplying the tidally influenced ranges in ground-water and surface-water levels in the aquifer by the ratio of proposed to current tidally influenced ranges in ground-water and surface-water levels in the tidal channel—this assumes a linear propagation of tidal pulses from the tidal channel to the aquifer. Under current tidal stage conditions, the estimated maximum distances where the tidal pulse in the fine sand aquifer exceeds 0.01 ft was 541.3 ft at site BHW497 (lower marsh) and 342.5 ft at site BHW499 (upper marsh). At site BHW497, the estimated maximum distances where the tidal pulse exceeds 0.05 and 0.1 ft were 233.8 and 101.4 ft, respectively. The tidal pulse at site BHW499 would exceed 0.05 ft for a distance of 34.8 ft. Following an increase in tidal stage to the values projected by the U.S. Army Corps of Engineers, the tidal pulse at site BHW497 would exceed 0.01, 0.05, and 0.1 ft at maximum distances of 662.2, 354.7, and 222.3 ft, respectively. The tidal pulse at site BHW499 would exceed 0.01 ft for a maximum distance of 419.8 ft and exceed 0.05 ft for a distance of 112.3 ft following the projected increases in marsh-channel tidal stages.

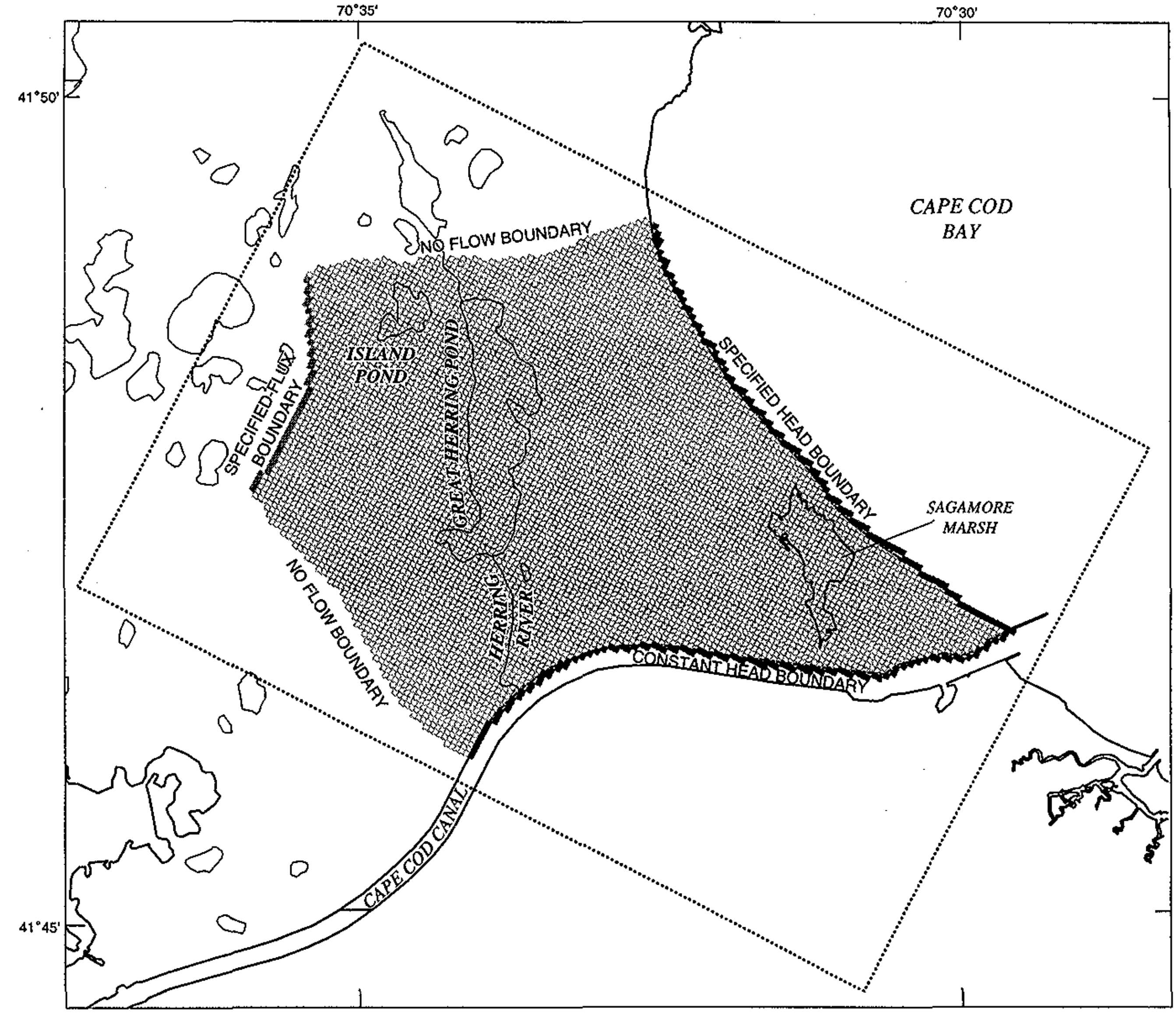
Propagation distances projected for the underlying sand aquifer were much higher than those projected for the marsh sediments. The larger propagation distance is a function of the higher aquifer diffusivity of the sand aquifer as compared to the marsh sediments. Aquifer diffusivities of the marsh sediments at the two marsh sites averaged 275 ft^2/d—the estimated aquifer diffusivity in the underlying sand and silt aquifer was about 225,000 ft^2/d.

Whether a marsh-generated tidal pulse is transmitted through the fine-grained marsh sediments or through the underlying aquifer is difficult to determine. The tidal pulse originating at the tidal channel for present and anticipated tidal-stage fluctuations does not propagate very far in the marsh sediments. Propagation distances are significantly higher in the underlying sand aquifer, but are still small compared to the size of the marsh; the distance between the tidal channel and the marsh edge is more than 600 ft along most of the northeastern edge of the marsh. Magnitudes of the tidal pulses evaluated in the calculations—0.01, 0.05, and 0.1 ft—are small as compared to natural fluctuations in the water table beneath the barrier island that arise from tidal fluctuations in Cape Cod Bay and from precipitation events (fig. 7).

The results of the analytical solutions are consistent with observations of ground-water level fluctuations along the northeastern edge of the marsh. Because tidal fluctuation in the water table was not discernible at site BHW492 (fig. 6), any marsh-generated fluctuations in the water table may be transmitted primarily through the marsh sediments; the distance of 250 ft between site BHW492 and the tidal channel is less than the projected propagation distance of a 0.01 ft tidal pulse in the fine sand aquifer of 342.5 ft. The tidal pulse originating in the upper marsh tidal channel has no discernible effect on water levels at sites BHW492 and BHW496 about 250 and 660 ft from the nearest tidal channel, respectively. The projected maximum rise in high tidal stages would not substantially increase ground-water-level fluctuations near the edge of the marsh. Given the small tidal fluctuations in the aquifer and the rapid attenuation of tidal pulses in the marsh sediments, the magnitude of any marsh-generated tidal pulses beneath the barrier island would be significantly smaller than tidal pulses originating from Cape Cod Bay and fluctuations arising from precipitation events. Overbank flooding would not be expected to result in a rise in ground-water levels. The low permeability of the marsh sediments and the fact that overbank water probably would not be in direct hydraulic connection to the underlying aquifer would attenuate the effects on water levels in the aquifer.

Numerical Analysis of Ground-Water-Flow System

A numerical analysis of the ground-water-flow system was done to evaluate the zone of contribution to the public-supply well at site BHW013 (the North Sagamore Water District's Beach Well) for current (1994) pumping conditions and to evaluate the response of the ground-water-flow system to proposed changes in tidal stage in Sagamore Marsh. A steady-state, three-dimensional model of ground-water flow was developed using the finite-difference computer code MODFLOW developed by McDonald and Harbaugh (1988). The finite-difference grid developed for the modeled area (fig. 13) is aligned with the finite-difference grid of the regional flow model of the Plymouth-Carver aquifer developed by Hansen and Lapham (1992). The two grids were aligned so that boundary conditions for the model of the Sagamore Marsh area (a subregional model) could be obtained from the results of the regional-scale model of the Plymouth-Carver aquifer.



Base from U.S. Geological Survey digital data
1:24,000, 1991
Universal Transverse Mercator projection
Zone 19

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

ACTIVE MODEL CELL

BOUNDARY OF FINITE-DIFFERENCE GRID

Figure 13. Extent of finite-difference model grid and lateral boundary conditions for the Sagamore Marsh area, southeastern Massachusetts.

Model Development

The model grid covers an area of about 27.2 mi^2, but the area of the ground-water-flow system that is actually simulated (the active modeled area) is only about 11 mi^2 (fig. 13). The lateral extent of the model was selected to include an area large enough to minimize the effect of model boundary conditions on ground-water heads calculated near Sagamore Marsh and on the zone of contribution delineated for supply well BHW013.

Grid

The finite-difference grid consists of 115 rows and 165 columns of uniformly-spaced cells each 200×200 ft on a side (fig. 13). The grid cells are one-twenty-fifth the size of those of the regional model of the Plymouth-Carver aquifer (Hansen and Lapham, 1992), which had a discretization of 1,000×1,000 ft. The model consists of four layers that extend from the water table to the bedrock surface. The vertical spacing was chosen to coincide with the hydrogeologic units in the study area (fig. 4).

The bottom altitude of cells in layer 1 (top layer) that are coincident with Island and Great Herring Ponds was set equal to the altitude of the bottom of each pond; pond bathymetry was obtained from Massachusetts Division of Fisheries and Wildlife (1993). The bottom altitude of cells in layer 1 of the model that contain marsh sediments coincides with the altitude of the bottom of these sediments, as determined from lithology data collected in the marsh (fig. 4). The bottom altitude of the remaining model cells in layer 1 were set equal to 0 ft above sea level. The bottom altitudes of layers 2 and 3 were set at 50 and 110 ft below sea level, respectively. This vertical spacing was based on the changes in lithology as described in the previous section "Hydrogeologic Units."

In the northwest part of the modeled area, the bottom altitude of layer 3 was truncated at 50 ft below sea level to coincide with the underlying bedrock surface, as reported by Hansen and Lapham (1992). The bottom altitude of layer 4 also coincides with the contact of the bedrock surface and glacial deposits, and extends from 110 to 185 ft below sea level.

Boundary Conditions and Stresses

Hydraulic boundaries of the simulated area include ground-water inflow from streams, ponds, wells, coastal saltwater bodies, the water table, and adjacent areas of the aquifer. The contact between unconsolidated, glacial sediments, and the underlying crystalline bedrock is a hydraulic boundary across which there is no ground-water flow. The northwestern part of the modeled area is an area of ground-water inflow from adjacent, upgradient parts of the aquifer (fig. 13). A specified-flux boundary condition was used to simulate the inflow of ground water across this boundary. The rate of inflow across the boundary was calculated by three methods. First, an inflow rate of 2.9 ft^3/s was obtained by multiplying the area between the northwestern boundary of the model and the water-table divide northwest of the model boundary by the areal recharge rate for the study area (about 27 in/yr) used by Hansen and Lapham (1992). The location of the water-table divide was obtained from the water-table map of the Plymouth-Carver aquifer published by Hansen and Lapham (1992). Second, an inflow rate of 2.5 ft^3/s was obtained from Darcy's law by use of measured hydraulic gradients along the northwestern boundary, estimates of transmissivity, and the cross-sectional area of the northwestern boundary of the model. Finally, an inflow rate of 3.2 ft^3/s was obtained from the results of the regional-scale flow model (Hansen and Lapham, 1992) across the cross-sectional area coincident with the northwestern boundary of the subregional model. The average of these three estimated inflow rates (2.9 ft^3/s) was distributed to the 118 active model cells along the northwestern boundary in proportion to the cross-sectional area and horizontal hydraulic conductivity of each cell.

When short-term (for example, tidal) fluctuations are averaged, coastal saltwater bodies along the southern and eastern boundaries of the model, such as Cape Cod Bay and the Cape Cod Canal (fig. 13) can be considered areas of constant water levels. These boundaries were simulated by means of a specified-head boundary condition in layer 1 of the model similar to previous studies on Cape Cod (Masterson and Barlow, 1994). Because these boundaries consist of saltwater, the saltwater heads were converted to equivalent freshwater heads by dividing the thickness of the saltwater body in each specified-head cell by 40.0, the ratio of the specific weight of freshwater (1.000 g/cm^3) to the difference between the specific weights of saltwater (1.025 g/cm^3) and freshwater. The thickness of the saltwater body for each cell was obtained from the bathymetric contours reported on the U.S. Geological Survey 1: 24,000 Sagamore, Massachusetts quadrangle map.

The northern and western hydraulic boundaries of the active modeled area are ground-water drainage divides. The location of the drainage divides were based on ground-water-flow lines drawn perpendicular to water-table contours in the modeled area for ground-water conditions of November 30 through December 2, 1984 (Hansen and Lapham, 1992) (fig. 1). The ground-water drainage divides were simulated as no-flow boundaries, across which ground water cannot flow. In the natural system, however, ground-water drainage divides may shift in response to seasonal, tidal, and other induced changes in ground-water levels.

The lower boundary of the model was identified as the contact between the unconsolidated glacial deposits and the underlying crystalline bedrock. Flow across this contact was assumed to be insignificant because of the low permeability of the crystalline bedrock relative to overlying glacial sediments. The lower boundary was therefore simulated as a no-flow boundary condition. The location of this no-flow boundary was obtained from a map showing the altitude of the bedrock surface for the study area (Hansen and Lapham, 1992).

The upper boundary of the model is defined by three boundary conditions that simulate the water table, streamflow, and ground-water seepage at Sagamore Marsh. The water table was simulated as a free-surface boundary condition that receives spatially variable rates of recharge. The altitude of the water table is calculated by the model for layer 1. The rate of recharge from precipitation specified for the steady-state model simulations, 27 in/yr, was obtained from the regional investigation of Hansen and Lapham (1992). At Island and Great Herring Ponds, the steady-state rate of recharge was reduced to account for evaporation from the pond surfaces; a specified value of 20 in/yr was obtained by subtracting the estimated rate of free-water-surface potential evaporation from the ponds, 28 in/yr (Farnsworth and others, 1982), from the average rate of precipitation in the study area (48 in/yr).

Recharge rates were decreased in some areas to account for changes in geology. In areas underlain by glaciolacustrine sediments, which have a lower hydraulic conductivity than glacial sands, the recharge rate was decreased to 6.8 in/yr, as was simulated in the regional-scale model (Hansen and Lapham, 1992). This lower recharge rate (6.8 in/yr) is based on the mean-annual ground-water runoff calculations of Morrissey (1983) for fine-grained sediments. This value may be a slight underestimate of the actual recharge due to the absence of surface runoff; however, the limited areal extent of the reduced recharge as compared to the overall modeled area would make these slight differences in recharge negligible in terms of the overall hydrologic budget and model calibration. In areas underlain by Sagamore Marsh, recharge was set at zero to account for the high rates of evapotranspiration and low rates of infiltration typical of salt marshes (Peter Weiskel, oral commun., 1995). Also, recharge was not specified for the marsh because it is assumed to be an area of ground-water discharge. The average recharge rate over the entire modeled area was about 25 in/yr.

Recharge was increased at the surface of Great Herring Pond to balance the surface-water inflows and outflows at the upgradient and downgradient ends of the pond from the Herring River. Measurements of streamflow entering and leaving Great Herring Pond indicated a net inflow to the aquifer from the pond of 2.72 ft^3/s in July 1986 (Hansen and Lapham, 1992). This increase in inflow to the aquifer was distributed uniformly as spatial recharge to the model cells that are coincident with Great Herring Pond and was combined with the pond recharge from precipitation previously corrected for evaporation.

The Herring River, which flows through Great Herring Pond, constitutes the only streamflow in the study area. Measurements of the Herring River indicate that the river is a losing stream along the reach from the outlet of Great Herring Pond to the gage near the Cape Cod Canal. Along this reach, the streamflow decreased from 7.28 to 6.35 ft^3/s in July 1986 (Hansen and Lapham, 1992). This losing reach of stream was simulated as a specified-flux boundary condition in the model. For this investigation, all streamflow loss was assumed to occur in the upper 1,000 ft of the stream, and, therefore, 0.93 ft^3/s of inflow was distributed uniformly to the first five model cells coincident with the Herring River, downgradient from Great Herring Pond.

The final boundary condition in layer 1 of the model is the ground-water seepage occurring at the Sagamore Marsh. Visual inspections in the marsh indicate ground-water seepage along the boundary between the low-permeability marsh sediments and the adjacent glacial sands; however, the actual rate of this seepage was not determined during this investigation. Ground-water seepage at the aquifer-marsh boundary was simulated in the flow model as a head-dependent-flux boundary that could only receive ground-water discharge. This boundary condition does not allow for flow from the marsh sediments to the underlying aquifer. Heads specified at the ground-water seeps were estimated from topographic contours shown on the U.S. Geological Survey 1: 24,000 Sagamore, Massachusetts quadrangle map. The tidally affected marsh channel also was simulated as a head-dependent flux boundary. This allows for ground water to discharge to the channel when the model-calculated head in the aquifer is higher than the stage in the channel, and allows for the possibility of surface-water discharge from the channel to the underlying aquifer when the simulated stage in the channel is higher than the model-calculated head in the underlying aquifer. The simulated stage in the marsh channel was based on the results of a surface-water model developed by the U.S. Army Corps of Engineers (Matthew Walsh, written commun., 1995).

The only stress on the simulated ground-water-flow system is ground-water pumping for public supply at the Black Pond and Beach Wells (BHW013) in the North Sagamore Water District. The Black Pond Well is the primary source of drinking water for the residents of the North Sagamore Water District and was pumped at an average rate of 0.28 Mgal/d in 1994 (Paul Gibbs, North Sagamore Water District, written commun., 1995). The Beach Well (BHW013) is used primarily as an auxiliary supply to meet increased demand during the summer season. The average pumping rate for the Beach Well for 1994 was 0.05 Mgal/d (Paul Gibbs, written commun., 1995). Ground-water withdrawal from these public-supply wells was simulated in the model as a specified flux boundary condition.

Hydraulic Properties

The hydraulic properties required for the ground-water modeling in this investigation are horizontal hydraulic conductivity and vertical hydraulic conductivity. The initial hydraulic conductivities used in the numerical model were obtained from the analysis of the aquifer test described in previous sections, and by comparing hydrogeologic sections (fig. 4) to hydraulic conductivities generalized for individual grain sizes from the results of previous investigations in the Plymouth-Carver and nearby Cape Cod aquifers (Guswa and LeBlanc, 1985; Hansen and Lapham, 1992; Barlow and Hess, 1993; Barlow, 1994; Masterson and Barlow, 1994; Masterson and others, 1996).

Generalized hydraulic conductivities were assigned for each of the hydrogeologic units described earlier and are shown in table 3. Hydraulic conductivity estimates initially were assigned to each model layer based on the lithologic boundaries shown in the hydrogeologic sections (fig. 4) and the conceptual-depositional model of glacial deposits for the study area previously discussed. Where lithologic changes occurred in a model layer, hydraulic conductivities were approximated based on thickness-weighted averages of hydraulic conductivity in a given model layer.

Initial hydraulic conductivities of the glacial and marine sediments in the flow model ranged from 1.0 to 350 ft/d (table 3). The coarser grained glacial sediments in the deltaic, moraine, and kame deposits were assigned hydraulic conductivities from 150 to 230 ft/d in the top two layers of the model and values as low as 30 to 70 ft/d in layers 3 and 4 of the model. The highest hydraulic conductivity of 350 ft/d was assigned to the beach deposits on the Cape Cod Bay side of the Sagamore Marsh in layer 1 of the model. The glacial sediments in the upper part of the flow system constitute the major aquifer in the area around the Sagamore Marsh and were assigned a hydraulic conductivity of 230 ft/d, which is consistent with the results of the aquifer-test analysis described in the previous section. The highest hydraulic conductivity used in the model was 50,000 ft/d and was assigned to model cells coincident with Island and Great Herring Ponds. The high hydraulic conductivity caused calculated hydraulic gradients in the ponds to be nearly zero, which is consistent with pond surfaces.

In general, the lowest hydraulic conductivities in the model were assigned to the glacio-lacustrine, marine, and marsh deposits. These deposits consist of fine sand, silt, and clay and constitute the confining

Table 3. Initial and calibrated hydraulic conductivity of hydrogeologic units for each layer of a ground-water-flow model for Sagamore Marsh, southeastern Massachusetts

[--, not present in model layer]

Hydrogeologic units	Hydraulic conductivity in feet per day for model layers							
	1		2		3		4	
	Initial	Cali-brated	Initial	Cali-brated	Initial	Cali-brated	Initial	Cali-brated
Glacial								
Deltaic deposits	230	230	230	230	70	70	30	30
Moraine	150	150	150	150	30	70	30	30
Kame	150	150	150	150	150	70	70	30
Glaciolacustrine deposits	30	50	--	--	--	--	--	--
Marine								
Beach deposits	350	150	--	--	--	--	--	--
Marsh deposits	1.0	.03	--	--	--	--	--	--
Marine deposits	--	--	10	50	--	--	--	--

units in the area around the Sagamore Marsh. Hydraulic conductivities specified in the model ranged from 1.0 ft/d in the marsh deposits to as high as 30 ft/d for the fine sand and silt of the glaciolacustrine deposits (table 3). The marsh hydraulic conductivity of 1.0 ft/d is significantly higher than values estimated from the tidal-response analytical method. The use of overestimates of hydraulic conductivity in the model allows for "worst case" model simulations; high marsh-sediment conductivities would allow for more drawdown of salty water from the tidal channels to the underlying aquifer and for more extensive propagation of marsh-generated tidal effects through the aquifer than would actually occur.

The vertical conductance, which is a measure of the vertical hydraulic conductivity used in MODFLOW, was specified between vertically adjacent model cells based on the relation discussed in McDonald and Harbaugh (1988). The vertical hydraulic conductivities required to calculate vertical conductances were based on ratios of horizontal to vertical hydraulic conductivity estimates for glacial sediments from the previous investigations in the Plymouth-Carver and Cape Cod aquifers. The ratios of horizontal to vertical hydraulic conductivity assumed in this investigation were 3:1 for hydraulic conductivities ranging from 225 to 350 ft/d; 5:1 for hydraulic conductivities ranging from 175 to 225 ft/d; 10:1 for hydraulic conductivities ranging from 125 to 175 ft/d; 30:1 for hydraulic conductivities ranging from 50 to 125 ft/d; 100:1 for hydraulic conductivities ranging from 1.0 to 50 ft/d; and 1:1 for hydraulic conductivities of 1.0 ft/d.

Calibration and Sensitivity

The numerical model developed for this investigation was calibrated by adjusting horizontal and vertical hydraulic conductivities in the model to provide the best match between measured and model-calculated water levels and pond levels (tables 3 and 4). Only hydraulic conductivity values were adjusted during the model-calibration process because these values were assumed to have the greatest uncertainty of all model input parameters. Recharge values were not varied in the calibration process because the values used in the model simulations are assumed to be more certain on the basis of results of the previous studies in the Plymouth-Carver and adjacent Cape Cod aquifers.

Most of the water-level data used for the model calibration process were collected in a synoptic water-level measurement during November 30 through December 2, 1984, and reported in Hansen and Lapham (1992). The data collected during this period was assumed to represent long-term average conditions in the modeled area (Hansen and Lapham, 1992).

Table 4. Measured heads for selected observation wells and pond sites, and model-calculated heads for average current conditions, Sagamore Marsh, southeastern Massachusetts

[Data from Hansen and Lapham (1992) unless otherwise noted. ft, foot]

Well identifier or pond site	Model cell location			Measured head (ft above sea level)	Model-calculated head (ft above sea level)	Difference (ft)
	Layer	Row	Column			
BHW013[1]	1	39	109	6.3	5.8	0.5
BHW206	1	24	87	3.0	11.0	-8.0
BHW286	2	38	109	6.6	5.9	.7
BHW290	1	73	73	19.0	27.4	-8.4
BHW295	1	46	85	17.1	19.8	-2.7
BHW296	1	83	78	9.9	19.2	-9.3
BHW297	1	89	78	8.4	15.7	-7.3
BHW298	1	88	86	3.6	5.1	-1.5
BHW300	1	66	76	20.8	26.2	-5.4
BHW488-53[1]	2	40	109	6.5	6.0	.5
BHW491-55[1]	2	38	116	1.5	3.8	-2.3
BHW492-5[1]	1	38	116	3.9	3.8	.1
BHW493-5[1]	1	40	119	2.9	3.5	-.6
BHW494-5[1]	1	38	113	3.5	4.0	-.5
BHW496-5[1]	1	42	126	2.7	2.5	.2
BHW497-19[1]	2	54	122	5.5	3.9	1.6
BHW498-5[1]	1	54	122	3.8	3.9	-.1
BHW499-21[1]	2	46	126	2.7	3.0	-.3
BHW500[1]	1	47	113	3.5	4.0	-.5
PWW220	1	60	45	37.1	37.4	-.3
PWW250	1	46	17	42.7	42.4	.3
PWW325	2	23	71	20.0	20.2	-.2
PWW327	2	25	75	19.0	19.0	.0
PWW437	1	24	61	23.3	25.7	-2.4
PWW485	1	84	40	38.3	39.0	-.7
Great Herring Pond	1	50	50	34.0	34.4	-.4
Island Pond	1	40	32	39.0	38.8	.2

[1]Analysis results obtained from current study.

Additional water-level information also was obtained in the area around Sagamore Marsh from observation wells installed as part of the aquifer test conducted during this investigation.

A total of 25 water-level measurements, 2 pond-level measurements, and the 45 ft water-table contour at the northwestern boundary were used in the model calibration. Of the 25 water-level measurements, 14 were from the November 30 through December 2, 1984, synoptic measurements reported in Hansen and Lapham (1992), and the remaining 11 water-level measurements were obtained during this investigation. The two pond levels were obtained from USGS topographic maps.

Generally, agreement between model-calculated and measured water levels at observation wells and ponds is close (table 4). The mean absolute error was 3.6 ft, which is about an 8-percent error over the entire slope of the water table (45 ft). The model-calculated water levels at the northwestern boundary were within 1 ft of the measured 45-foot water level, and, therefore, the specified-flux boundary determined in the previous section was not adjusted during model calibration.

Differences between model-calculated and measured water levels were largest near the Great Herring Pond/Herring River system (BHW290, BHW296, BHW297, BHW300), and near the coast (BHW206). The large differences between model-calculated and measured heads (greater than 5 ft) in the area of Great Herring Pond may be attributed to an oversimplification of the simulated ground-water/ surface-water interaction, which cannot account for the measured head loss occurring between the pond and stream, and the underlying aquifer, resulting in higher model-calculated heads.

The large difference in model-calculated and measured head (about 8 ft) near the coast may be the result of the model discretization being too coarse to accurately simulate steep hydraulic gradients near areas of coastal ground-water discharge. Also, the time periods in which the measurements were made may not be representative of mean water levels due to tidal fluctuations. In addition, ground-water discharge may occur at some distance offshore—the simulation of the salt-water interface as being at or near the coast may focus simulated ground-water discharge over a smaller area and would result in artificially high heads at the coast.

The initial estimates of horizontal hydraulic conductivity and vertical conductance were adjusted within reasonable limits during model calibration (table 3). The largest changes in hydraulic conductivities were made for the beach deposits on the eastern side of the Sagamore Marsh in layer 1 and the underlying marine clay in layer 2. Water levels showed large changes in response to changes in the horizontal hydraulic conductivities and the corresponding vertical conductances in this area of the model. Therefore, the vertical connection between these two deposits apparently has a significant control on the water discharging to the coast.

Water levels near Great Herring Pond and Herring River showed little change in response to large changes in the vertical and horizontal connections of the simulated Great Herring Pond and the surrounding aquifer. These connections were decreased by as much as four orders of magnitude from initial estimates to create a larger head loss between the pond and the underlying aquifer, and yet water levels in this vicinity declined by less than 1 ft. Aquifer recharge also was decreased by 5 percent to improve the match between measured and model-calculated water levels.

Once the flow model was considered calibrated, the hydraulic budget was calculated for current (1994) conditions. Components of the calculated hydrologic budget of the modeled area are given in table 5. Total inflow to the modeled area is 23.8 ft^3/s, of which 84 percent is recharge from precipitation and the remaining 16 percent is inflow from ground-water flow across the northwestern boundary and beneath the Herring River. Nearly all the water leaving the modeled area (93 percent) discharges to the coast. Ground-water discharge to seeps along the perimeter of Sagamore Marsh only represents about 5 percent of the total water leaving the simulated ground-water system, and ground-water pumping in the North Sagamore Water District for current (1994) conditions represents the remaining 2 percent. There was no simulated ground-water seepage directly to the marsh channel for current conditions.

Table 5. Hydrologic budget for the aquifer system calculated for average current conditions, Sagamore Marsh, southeastern Massachusetts

Budget component	Rate of flow: Cubic feet per second	Rate of flow: Million gallons per day
Inflow		
Recharge	20.0	12.9
Northwestern boundary	2.9	1.9
Herring River	.9	.6
Total inflow	23.8	15.4
Outflow		
Pumping from wells	0.5	0.3
Discharge to marsh	1.1	.8
Discharge to coast	22.2	14.3
Total outflow	23.8	15.4

Simulation of Ground-Water-Flow System

Ground-water flow was simulated near Sagamore Marsh for current conditions and for increased tidal-stage conditions. The analysis of the ground-water-flow system included a comparison of water levels before and after the proposed marsh restoration to determine possible effects of increased tidal stage on ground-water levels in and around the marsh. The zone of contribution to North Sagamore Water District's Beach Well also was determined by use of the flow model for current and increased tidal-stage conditions.

The zone of contribution for the Beach Well was determined by particle tracking, which allows for the delineation of the zone of contribution for selected ground-water sinks such as pumping wells. By use of particle-tracking simulations, the particles of water can be tracked from areas of ground-water recharge to areas of ground-water discharge, thereby identifying the area at the water table that is the source of water for the ground-water sink. A particle-tracking program, MODPATH (Pollock, 1994), was used to calculate flow paths from the results of the ground-water-flow model. The only parameter in addition to those used in the numerical model that is required for the particle-tracking analysis is porosity, which is required for time-of-travel estimates and does not otherwise affect the size, shape, or location of the zone of contribution to the well. Because traveltimes are not the focus of this study, and no information is available on the porosity of the regional aquifer system near Sagamore Marsh, a uniform value of 0.30, which is based on published values of porosity for sand, was selected for this investigation (Freeze and Cherry, 1979).

Current (1994) Conditions

The model-calculated zone of contribution for the Beach Well, which is defined as the area at the water table through which recharge entering the ground-water-flow system supplies water to a pumping well at a given rate, was calculated by tracking 125 particles backward from the simulated location of the well screen to the model-calculated water table for 1994 pumping conditions (fig. 14). The number of particles used in this simulation (125) was chosen arbitrarily to adequately represent the water particles in the model node containing the public supply well.

The results of the model simulations indicate that the source of water for the Beach Well pumping at the current rate is ground-water recharge that occurs primarily between the pumped well and Great Herring Pond. The results also indicate that the zone of contribution for the pumping well extends to Great Herring Pond and may include areas adjacent to, and downgradient of the pumping well. However, the results do not indicate that the zone of contribution for the pumping well will extend into the area of Sagamore Marsh for current pumping conditions.

The zone of contribution calculated for the Beach Well, which has been used primarily as an auxiliary supply to provide additional water to meet increased demand during the summer, was based on an average daily pumping rate of 8,380 ft^3/d (or 0.063 Mgal/d) for the entire 1994 calendar year. The total amount of water pumped from the well in 1994 was 22.88 Mgal (Paul Gibbs, written commun., 1995). Although the Beach Well was not pumped every day in 1994, the pumping rate was substantially higher than 0.063 Mgal/d on those days in which the well was actually pumped. A particle-tracking analysis in which pumping and recharge rates could be varied with time would require a transient particle-tracking analysis, which was beyond the scope of the current investigation.

A second simulation was made using an increased pumping rate at the well. All public-supply demands for the North Sagamore Water District were assumed to be met by pumping at the Beach Well; the simulated pumping rate at the Beach Well was increased from an average daily pumping rate of 8,380 to 43,124 ft^3/d (Paul Gibbs, written commun., 1995). This nearly seven-fold increase in the average daily pumping rate at the Beach Well resulted in a substantially larger zone of contribution to the well than that determined for average 1994 pumping conditions, yet the zone of contribution still extends northwestward of the well toward Great Herring Pond (fig. 14). Ground-water flow from the marsh to the well was not induced by pumping in either of the model simulations.

Increased Tidal Stage in Marsh

As part of the proposed changes in saltwater flow to the marsh, the U.S. Army Corps of Engineers is considering the possibility of increasing the culvert size at the entrance to the marsh to increase tidal flow into the marsh. The maximum proposed increase in culvert size is from the current single, 4-foot diameter culvert to two culverts with the dimensions of 10×20 ft. This increase in culvert size is projected to increase the tidal exchange in the marsh such that the high-tide stage in the marsh channel increases by about 1 foot in the lower marsh and about 0.6 ft in the upper marsh (Matthew Walsh, written commun., 1995).

The numerical model was used to evaluate the effect of the increased stage in the marsh channel on ground-water flow near Sagamore Marsh. Model-calculated ground-water levels indicated that no change in ground-water levels in and beneath the marsh would result from increased tidal stages.

Changes in model-calculated ground-water levels between current and increased tidal-stage conditions did not occur and may be a result of the large model discretization (200×200 ft) relative to the marsh-channel width (about 10 ft). The large model discretization may result in an under-projection of water levels immediately adjacent to the marsh channel, and, therefore, this model discretization may not be adequate to project water-level changes immediately adjacent to the marsh channels. Model results do indicate that the effect of the increased tidal-channel stage on the ground-water table would dissipate rapidly over a short distance (in one model cell) and does not affect ground-water levels near the beach at Cape Cod Bay or the Beach Well. Also, the results of the numerical model are consistent with the analytical solution described in previous sections, where the effect of post-restoration tidal-channel stage fluctuations of greater than 0.01 ft in the marsh sediments dissipated in less than 50 ft from the marsh channel.

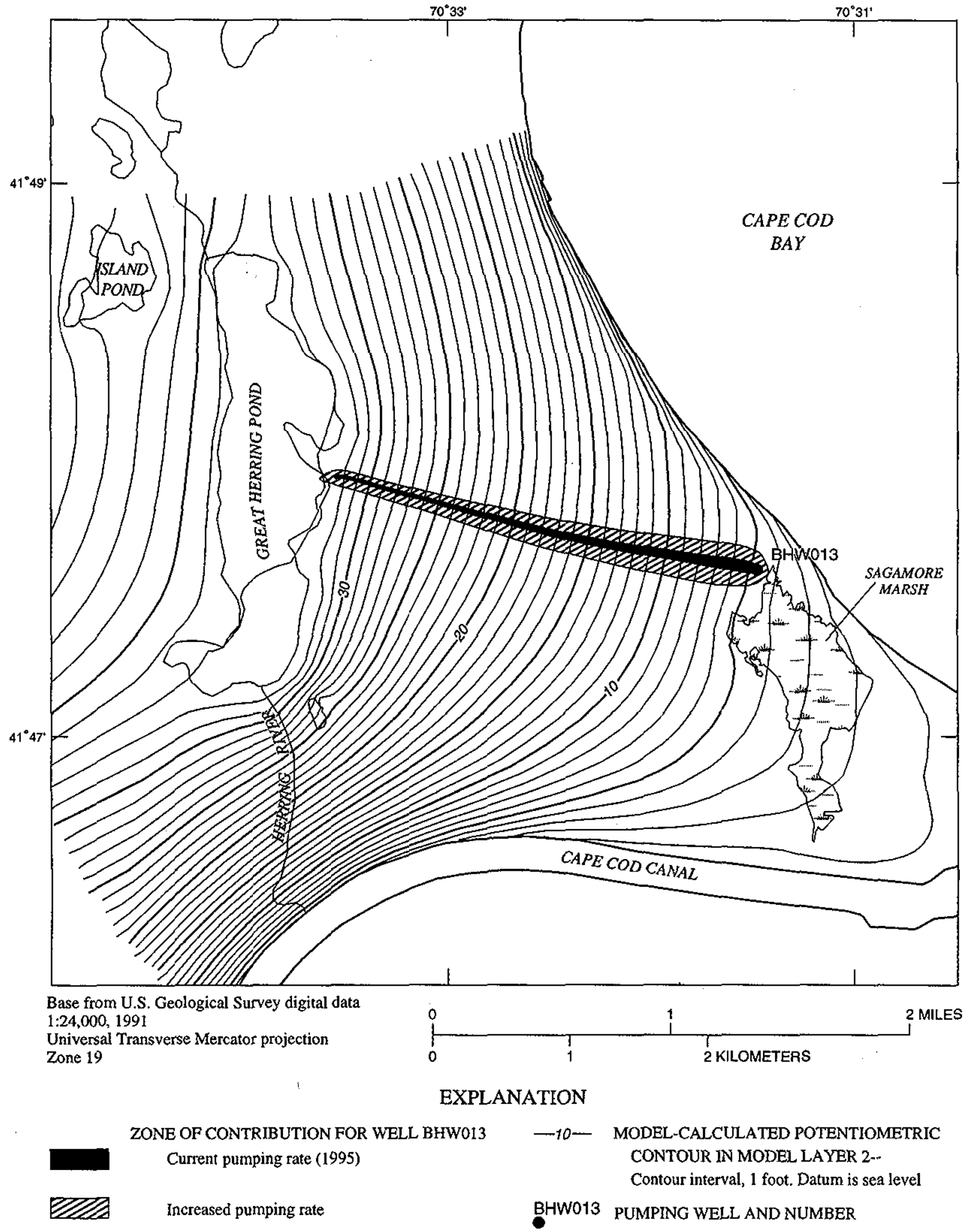


Figure 14. Zone of contribution to site BHW013 near Sagamore Marsh for current and increased pumping conditions and model-calculated heads in model layer 2 for current pumping conditions, southeastern Massachusetts.

SUMMARY AND CONCLUSIONS

Sagamore Marsh is a salt marsh in a coastal area of southeastern Massachusetts that is bounded to the east by Cape Cod Bay and to the south by the Cape Cod Canal. Saltwater inflow from the Cape Cod Canal to the marsh is constricted by a 4-foot diameter culvert. In an effort to restore salt-marsh and estuarine habitat in the marsh, the U.S. Army Corps of Engineers has proposed to increase the amount of saltwater that enters the marsh by widening the culvert between the Cape Cod Canal and the marsh. A numerical model by the U.S. Army Corps of Engineers estimates that high-tide stages in tidal channels will increase by less than 1.0 ft in the lower part of the marsh and by less than 0.6 ft in the upper part of the marsh.

The investigation was done to determine whether the proposed increase in the amount of saltwater entering the marsh at high tide would be likely to increase hydraulic heads in the underlying aquifer and whether the proposed restoration of the marsh would be likely to cause saltwater intrusion into an adjacent large-capacity public-supply well. In April 1995, the U.S. Geological Survey, in cooperation with the Army Corps of Engineers, began an investigation into the geology and ground-water hydrology of the Sagamore Marsh area to improve the understanding of the local hydrogeologic framework and ground-water-flow system and to address some of the concerns regarding how proposed changes in tidal-channel stage might affect the ground-water-flow system.

The regional geology is characterized by sequences of coarse-grained glaciofluvial outwash and finer grained glaciolacustrine, moraine, and till deposits that are part of the regional aquifer system known as the Plymouth-Carver aquifer system. In the area around Sagamore Marsh, these deposits consist of glaciolacustrine and deltaic sediments and extend to a depth of greater than 175 ft; the bedrock surface is estimated to be about 200 ft below land surface. Four major hydrogeologic units were defined in the glacial sediments: (1) shallow glaciolacustrine sediments consisting of brown silt and sandy clay, (2) underlying deltaic sediments consisting of fine to coarse brown sand, (3) glaciolacustrine sediments consisting of interbedded fine to coarse sand, silt, and clay; and (4) glaciolacustrine sediments consisting of fine gray sand and silt. The fine to coarse deltaic sand constitutes an important aquifer in the Sagamore Marsh area.

Sagamore Marsh influences shallow ground-water flow near the marsh and shallow ground water discharges along the edge of the marsh. Although most of the regional flow system is unconfined, the low vertical and horizontal hydraulic conductivity of the fine-grained glaciolacustrine sediments along the western edge of the marsh and of the fine-grained marsh sediments cause confining conditions beneath the marsh; for this reason, the regional flow system is referred to as a semiconfined flow system near the marsh. Unconfined (or water table) conditions prevail in the surficial marsh sediments, beyond the western and northwestern extent of the confining deposits, and along a barrier beach on the northeastern side of the marsh; confined conditions prevail just beneath the marsh sediments and along at least the northwestern edge of the marsh near public-supply well BHW013.

Tidal ranges in the marsh tidal channels were between 1.0 and 1.5 ft and tidal ranges in Cape Cod Bay were on the order of 9 ft during the period of study. Tidal pulses from tidal channels and Cape Cod Bay were rapidly attenuated in the ground-water system. Tidal ranges in the water table beneath the barrier beach were less than 0.1 ft along the northeastern edge of the marsh and about 0.5 ft near Cape Cod Bay. Tidal ranges in the regional aquifer were between 0.1 and 0.2 ft. Tidal pulses beneath the barrier beach were more in phase with tidal pulses originating from Cape Cod Bay, whereas tidal pulses in the regional aquifer were more in phase with tidal pulses originating from tidal channels in Sagamore Marsh.

A 5-day aquifer test was done as part of the study to determine the response of the ground-water-flow system near the marsh to pumping at a large-capacity public-supply well near the marsh, and to determine the hydraulic properties of the regional aquifer near the marsh. After 5 days of pumping, drawdown at the pumped well was 17.5 ft below the nonpumping (static) water level and drawdown in wells screened at the same horizon as the supply well at distances of from 100 to 725 ft from the supply well ranged from 4.92 to 1.67 ft. At the observation well closest to the marsh, drawdown at the end of the 5-day test was 3.18 ft. A drawdown of 0.37 ft was measured at a well about 1,450 ft from the pumping well. Results of the aquifer test were used to estimate hydraulic properties of the aquifer near the marsh. The estimates are: a transmissivity (T) of from 9,300 to 10,900 ft^2/d, a horizontal hydraulic conductivity (K_H) of from 181 to 213 ft/d, a ratio of vertical to horizontal hydraulic conductivity (K_Z/K_H) of 1:44, a ratio of storage coefficient to specific yield (S/S_y) of 0.09, a storage coefficient (S) of 4.4×10^{-4} to 2.6×10^{-3} and a specific yield (S_y) ranging from 0.01 to 0.03. The low values of K_Z/K_H and of S_y probably result from the presence of a hydrogeologic unit of glaciolacustrine silt and clay at the top of the stratigraphic column near the supply well.

The diffusivity (T/S) of the marsh deposits at two sites in the marsh was determined from the ratio of tidal ranges in tidal channels to those in adjacent wells. In the lower marsh, where the marsh sediments were coarser grained, aquifer diffusivity was estimated to be 380 ft^2/d; in the upper marsh, diffusivity was estimated to be 170 ft^2/d. The two values correspond to hydraulic conductivities of 2.5×10^{-3} and 1.7×10^{-3} ft/d, respectively. These values are between the ranges of values reported for marsh peat and marine clay, respectively, and are consistent with the lithology at the sites.

The calculated aquifer diffusivities were used to estimate the maximum distances from the tidal channels where tidal pulses in the ground water would exceed 0.01 ft, using an analytical-modeling technique. Estimates were made using current high-tide stages and increased high-tide stages predicted following marsh restoration. In the upper marsh, the maximum distance where tidal ranges in the aquifer would exceed 0.01 ft for current conditions is 24.4 ft. When the increased tidal stages were used, the maximum distance was 26.7 ft. Maximum distances estimated for the lower marsh site for present and maximum predicted high-tide stages were 37.1 and 42.0 ft, respectively. The data indicate that tidal pulses are rapidly attenuated in the aquifer and that changes in tidal stages in the channels and in flooded areas of the marsh will have little effect on ground-water levels near the marsh. The analytical model also was used to predict maximum distances where tidal pulses would propagate in the underlying fine sand aquifer. Diffusivities in the aquifer were estimated from lithology and aquifer test results. Maximum distances where tidal pulses exceeded 0.01, 0.05, and 0.1 ft in the sand aquifer beneath the lower marsh were 662.2, 354.7, and 222.3, respectively. Tidal pulses in the sand aquifer beneath the upper marsh exceeded 0.01 ft for a distances as much as 419.8 ft and exceeded 0.05 ft for a distance as much as 112.3 ft. Fluctuations of this magnitude are much smaller than fluctuations caused by tidal fluctuations in Cape Cod Bay and by natural precipitation events.

A numerical ground-water-flow model was developed to represent the Sagamore Marsh area. Results of the model simulations indicate that the zone of contribution to the public-supply well near the marsh extends from the well northwestward toward Great Herring Pond and that simulated increases in marsh-channel tidal stage have a negligible effect on the location of the zone of contribution to the well. Model results are consistent with field data and with the analytical-modeling results, which showed that tidal pulses originating from the tidal channels extend only about 42 ft laterally into the aquifer, which is less than the model discretization of 200 ft. Ground-water flow from the marsh to the well was not induced by pumping in any of the model simulations.

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APPENDIX F

MONITORING PLAN

APPENDIX F

MONITORING PLAN

1.0 PLANS AND SPECIFICATIONS PHASE (Baseline Data Collection)

1.1 Data Collection

1.1.1 <u>Survey</u>

Survey one cross-section in the vicinity of Transect 1, and one cross-section between Transects 2 and 4.

Install approximately ten oak reference stakes along each cross-section in the overbank areas and establish the top elevation of each.

Install two tide boards along the cross-section between Transects 2 and 4, one in each of the primary channels, and establish the elevation of each.

Check the existing four tide boards, re-install if required, and establish the elevation of each.

1.1.2 <u>Hydraulics</u>

Record water surface elevations at the six tide boards during a spring and/or mean and/or neap tide event.

Record water surface elevations at representative reference stakes in the overbanks during a spring and/or mean and/or neap tide event.

Use the above information to perform a final calibration of the hydraulic model prior to final design.

1.1.3 <u>Ecology</u>

Establish ten permanent sample stations along each of the two surveyed cross-sections, one at each of the ten stakes.

At each of the twenty permanent stations, record the depth of soil water during low tide; depth of flooding relative to the surface elevation of the marsh at high and low water during spring and neap tide phases; plant species composition and percent cover; height and density of *Phragmites*; and height of *Spartina alterniflora*.

Establish three permanent plots in the tidal channel to monitor eelgrass. Measure percent cover, height, and density of eelgrass plants.

Survey the horizontal location and vertical elevation of the Four-toed salamander habitat found at the south end of the project site east of the tidal channel. The habitat is estimated to be between elevation 4.0 and 6.0 feet NGVD. In the area of the Four-toed salamander habitat, survey vegetation to quantify the type and extent of habitat available to the species, obtain baseline salinity measurements in the small creeks present in the species' habitat, and conduct a population survey.

1.1.4 Groundwater

Obtain monthly water sample analyses for the "Beach Well" which the North Sagamore Water District submits to the DEP Div. of Water Supply from the DEP Div. of Water Supply for the prior and current year, and document salinity levels.

Obtain records of pumping rate from the Water District for the prior and current year to establish whether pumping rates increase, decrease, or remain constant during the monitoring period.

Measure and record groundwater levels in the five existing drive points on the perimeter of the marsh once per month.

Measure and record water levels through several tidal cycles in drive points and tidal channel gages to check predictions of the effect of increased tide range on groundwater range.

Measure and record specific conductance in the Beach Well and the ten drilled wells in the vicinity of the Beach Well once per month.

Measure and record baseline chloride levels in the Beach Well and the ten drilled wells in the vicinity of the Beach Well.

1.2 Reporting

A report will be written documenting the baseline data, and will be completed at the end of the Plans and Specifications phase.

2.0 MONITORING PHASE

2.1 Data Collection

2.1.1 Hydraulics

Record water surface elevations at the six tide boards during a spring and/or mean and/or neap tide immediately after construction.

Record water surface elevations at the reference stakes in the overbanks during a spring and/or mean and/or neap tide immediately after construction.

Compare the above information to estimates from the hydraulic model immediately after construction.

2.1.2 Ecology

At each of the twenty permanent stations, record the depth of soil water during low tide; depth of flooding relative to the surface elevation of the marsh at high and low water during spring and neap tide phases; plant species composition and percent cover; height and density of *Phragmites*; and height of *Spartina alterniflora*. Sampling will be conducted immediately following implementation, and during August of each year for five years following implementation.

At each of the three eelgrass plots, Measure percent cover, height, and density of eelgrass plants. Sampling will be conducted during August of each year for three to five years following implementation, depending on sampling results.

Contract for color aerial photography of the marsh to be taken at the end of the fifth growing season, at a scale of approximately 1" = 600'. Map vegetation in the marsh using the aerial photography and ground-truthing, and compare to the 1993 color photos at the same scale.

In the area of the Four-toed salamander habitat, survey vegetation to quantify the type and extent of habitat available to the species, monitor the salinity in the small creeks present in the species' habitat, and conduct annual population surveys.

2.1.3 Groundwater

Obtain monthly water sample analyses for the "Beach Well" which the North Sagamore Water District submits to the DEP Div. of Water Supply from the DEP Div. of Water Supply for the prior year and the five year monitoring period, and document salinity levels.

Obtain records of pumping rate from the Water District for the prior year and the five year monitoring period.

Measure and record groundwater levels in the five existing water-table wells on the perimeter of the marsh once per month for the first two years, and once every three months for the next three years.

Measure and record specific conductance in the Beach Well and the ten drilled wells in the vicinity of the Beach Well once per month for the first year, and once per month from May through October for the next four years.

2.2 Reporting

A yearly report will be written documenting the results of the yearly data collection, providing conclusions and recommendations.

APPENDIX G

MCACES COST ESTIMATE

SAGAMORE MARSH RESTORATION
DPR
6 x 12 W/Stop Logs

Designed By: NED-ED-D
Estimated By: NED-ED-C

Prepared By: John Yen, Cost Engineer

Preparation Date: 09/05/96
Effective Date of Pricing: 05/03/96
Est Construction Time: 180 Days

Sales Tax: 0.00%

1. An existing 48 inch RCP culvert and channel system that connect the marsh to the canal will be enlarged. The new culvert and channel will be sized to restore tidal flushing and salinity levels in the marsh.

2. The scope of work consist of widening the existing channel, installing 6'x12' box culvert, installing 2 sluice gates and 2 stop logs.

3. This estimate is for a scheme with an opening of 6'x12' selected after many other schemes with different sizes estimated for the PM. The total costs estimate for the particular scheme include:

Contingency (15%)
PED (15%)
Construction Management (10%)

2. Escalation is included to the date when report is complete in September 1996 and is based on Civil Works Construction Cost Index System (CWCCIS).

3. Plans and quantity data have been provided by CENED-ED-D and modified by PM.

SUMMARY REPORTS SUMMARY PAGE

DETAILED ESTIMATE DETAIL PAGE

BACKUP REPORTS BACKUP PAGE

* * * END TABLE OF CONTENTS * * *

		QUANTY	UOM	CONTRACT	DES CONT	ESCALATN	CONTINGN	PED	CON MGMT	TOTAL COST	UNIT COST	NOTES
1	SAGAMORE MARSH											
1.01	Scheme 5 - (											
1.01.01	Excavatio	1.00	EA	59,149	0	422	8,936	10,276	7,878	86,661	86661.17	
1.01.02	Backfill	1.00	EA	124,243	0	886	18,769	21,585	16,548	182,032	182031.59	
1.01.03	Precast C	231.00	LF	128,710	0	918	19,444	22,361	17,143	188,576	816.34	
1.01.04	Sluice Ga	2.00	EA	152,020	0	1,084	22,966	26,410	20,248	222,728	111364.21	
1.01.05	Stop Log	1.00	EA	33,606	0	240	5,077	5,838	4,476	49,237	49236.63	
1.01.06	Remove an	1.00	EA	1,598	0	11	241	278	213	2,342	2341.55	
1.01.07	Remove an	1.00	EA	6,034	0	43	912	1,048	804	8,840	8840.42	
1.01.08	Remove an	200.00	LF	8,683	0	62	1,312	1,508	1,156	12,721	63.61	
1.01.09	Wing Wall	3.00	EA	18,330	0	131	2,769	3,185	2,441	26,856	8952.04	
1.01.10	Remove an	200.00	LF	8,414	0	60	1,271	1,462	1,121	12,327	61.64	
1.01.11	Sheetpile	3500.00	SF	107,563	0	767	16,250	18,687	14,327	157,594	45.03	
1.01.12	Constr.Re			12,027	0	86	1,817	2,089	1,602	17,621		
1.01.13	Constr.Re			9,779	0	70	1,477	1,699	1,302	14,327		
	TOTAL Scheme 5			670,156	0	4,780	101,240	116,426	89,260	981,862		
	TOTAL SAGAMORE	1.00	EA	670,156	0	4,780	101,240	116,426	89,260	981,862	981861.96	
	TOTAL SAGAMORE	1.00	EA	670,156	0	4,780	101,240	116,426	89,260	981,862	981861.96	

		QUANTY	UOM	DIRECT	FIELD OH	HOME OFC	PROFIT	BOND	TOTAL COST	UNIT COST
1	SAGAMORE MARSH RESTORATION									
1.01	Scheme 5 - (6'x12'W/Stop Logs)									
1.01.01	Excavation	1.00	EA	45,155	4,516	4,222	4,365	891	59,149	59149.31
1.01.02	Backfill	1.00	EA	94,848	9,485	8,868	9,169	1,873	124,243	124243.00
1.01.03	Precast Concrete Conduit(6'	231.00	LF	98,258	9,826	9,187	9,499	1,940	128,710	557.18
1.01.04	Sluice Gate (6'X12')	2.00	EA	116,053	11,605	10,851	11,219	2,291	152,020	76010.01
1.01.05	Stop Log	1.00	EA	25,655	2,565	2,399	2,480	507	33,606	33605.74
1.01.06	Remove and Reconst 32'x15'	1.00	EA	1,220	122	114	118	24	1,598	1598.19
1.01.07	Remove and Reconst 70'x25'	1.00	EA	4,606	461	431	445	91	6,034	6033.90
1.01.08	Remove and Replace Guide Ra	200.00	LF	6,629	663	620	641	131	8,683	43.41
1.01.09	Wing Walls	3.00	EA	13,993	1,399	1,308	1,353	276	18,330	6110.08
1.01.10	Remove and Replace Wood Rai	200.00	LF	6,423	642	601	621	127	8,414	42.07
1.01.11	Sheetpiles	3500.00	SF	82,115	8,211	7,678	7,938	1,621	107,563	30.73
1.01.12	Constr.Remove Temp.Channel			9,181	918	858	888	181	12,027	
1.01.13	Constr.Remove Temp.Gravel R			7,465	747	698	722	147	9,779	
	TOTAL Scheme 5 - (6'x12'W/Stop Lo			511,602	51,160	47,835	49,458	10,101	670,156	
	TOTAL SAGAMORE MARSH RESTORATION	1.00	EA	511,602	51,160	47,835	49,458	10,101	670,156	670155.50
	TOTAL SAGAMORE MARSH RESTORATION	1.00	EA	511,602	51,160	47,835	49,458	10,101	670,156	670155.50
	Escalation to Const. Midpoint								4,780	
	SUBTOTAL								674,935	
	Contingencies								101,240	
	SUBTOTAL								776,175	
	Planning, Engineering and Design								116,426	
	SUBTOTAL								892,602	
	Construction Management								89,260	
	TOTAL INCL OWNER COSTS								981,862	

	QUANTY	UOM	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
1 SAGAMORE MARSH RESTORATION									
1.01 Scheme 5 - (6'x12'W/Stop Logs)									
1.01.01 Excavation	1.00	EA	754	24,938	20,217	0	0	45,155	45155.02
1.01.02 Backfill	1.00	EA	661	22,028	10,129	62,691	0	94,848	94848.03
1.01.03 Precast Concrete Conduit(6'X12'	231.00	LF	150	4,497	3,761	90,000	0	98,258	425.36
1.01.04 Sluice Gate (6'X12')	2.00	EA	372	16,003	5,217	94,833	0	116,053	58026.61
1.01.05 Stop Log	1.00	EA	45	1,357	1,208	23,090	0	25,655	25654.87
1.01.06 Remove and Reconst 32'x15' Road	1.00	EA	18	616	235	370	0	1,220	1220.07
1.01.07 Remove and Reconst 70'x25' Road	1.00	EA	78	2,607	830	1,169	0	4,606	4606.33
1.01.08 Remove and Replace Guide Rail	200.00	LF	120	3,742	70	2,816	0	6,629	33.14
1.01.09 Wing Walls	3.00	EA	204	6,022	654	7,318	0	13,993	4664.48
1.01.10 Remove and Replace Wood Rail	200.00	LF	100	3,092	75	3,256	0	6,423	32.12
1.01.11 Sheetpiles	3500.00	SF	640	20,585	15,093	46,436	0	82,115	23.46
1.01.12 Constr.Remove Temp.Channel Cros			65	2,119	832	6,230	0	9,181	
1.01.13 Constr.Remove Temp.Gravel Rd.			37	1,279	660	5,527	0	7,465	
TOTAL Scheme 5 - (6'x12'W/Stop Logs)			3,244	108,884	58,981	343,736	0	511,602	
TOTAL SAGAMORE MARSH RESTORATION	1.00	EA	3,244	108,884	58,981	343,736	0	511,602	511601.70
TOTAL SAGAMORE MARSH RESTORATION	1.00	EA	3,244	108,884	58,981	343,736	0	511,602	511601.70
Prime Contractor's Field Overhead								51,160	
SUBTOTAL								562,762	
Prime Contractor's Home Ofc. Overhead								47,835	
SUBTOTAL								610,597	
Prime Contractor's Profit								49,458	
SUBTOTAL								660,055	
Prime Contractor's Bond								10,101	
TOTAL INCL INDIRECTS								670,156	
Escalation to Const. Midpoint								4,780	
SUBTOTAL								674,935	
Contingencies								101,240	
SUBTOTAL								776,175	
Planning, Engineering and Design								116,426	
SUBTOTAL								892,602	
Construction Management								89,260	
TOTAL INCL OWNER COSTS								981,862	

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST

1.01.01. Excavation

<02000 0000 Site Work>
<02200 0000 Earthwork>
<02221 0000 Trenching, Backfilling, And Compaction>
<02221 1000 Trenching And Continuous Footing Excavation>
<Note - Machine Prices Are For Piled Earth Only>
<02221 1200 By Hydraulic Excav 1/2 To 3/4 Cy Capacity>

	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
L MIL AA Trench 1/2 C					0.09	3.07	2.05	0.00	0.00	5.12	
Y Hyd Exc, H	6184.00	CY	CODEA	22.23	557	18,999	12,690	0	0	31,689	5.12
vy Soil											
51 CY/Hr (40M3)/Hr											

<02200 0000 Earthwork>
<02225 0000 Bulk Excavation>
<02225 3000 Hauling - Includes Time For Loading, Travel,>
<Dump And Misc. Choose Prod Based On Cycle Time Or Distance. Note ->
<Pricing Does Not Include Cost For Excavation And Loading. See Csi>
<02225/2000 For Excav- Ation And Loading Costs>
<02225 3200 Trucks 12 LCY 30 mph>

	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
L AF AA Hauling 12 L					0.04	1.20	1.52	0.00	0.00	2.72	
CY 6 Mile	4947.00	CY	COEID	25.01	198	5,939	7,527	0	0	13,466	2.72
TOTAL Excavation	1.00	EA			754	24,938	20,217	0	0	45,155	45155.02

1.01.02. Backfill

1.01.02.01. Gravel

<02000 0000 Site Work>
<02200 0000 Earthwork>
<02221 0000 Trenching, Backfilling, And Compaction>
<02221 5000 Backfill Trenches - W/O CompactIon>

	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
USR AA Backfill w/6					0.10	3.53	1.34	0.00	0.00	4.87	
0 HP Tr Doze	1572.00	CY	CODTA	15.00	157	5,547	2,114	0	0	7,660	4.87
r											
Without Compaction											

<02221 0000 Trenching, Backfilling, And Compaction>

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
<02221 6000 Spread Dumped Fill Or Gravel W/O Compaction>											
<Note - W/Dozer In An Open Area>											
M AF AA Spread Borro					0.01	0.51	0.58	14.00	0.00	15.09	
w W/Dozer	1572.00	CY	CODTE	90.00	22	807	910	22,008	0	23,725	15.09
TOTAL Gravel	1572.00	CY			179	6,354	3,024	22,008	0	31,385	19.97
1.01.02.02. Sone Protection rip-rap											
<02000 0000 Site Work>											
<02260 0000 Slope Protection>											
<02261 0000 Rip Rap>											
<02261 1000 Random - Filter Stone Dumped From Trucks ->											
<Machine Placed Slope Protection (Keyed) Estimator To Adjust Material>											
<Costs As Required>											
B MIL AA Rip Rap, 10#					0.22	7.17	3.19	18.00	0.00	28.36	
to 100# Pie	2090.00	CY	COETF	18.09	462	14,984	6,676	37,620	0	59,280	28.36
ces											
Random, Dumped from Truck											
TOTAL Sone Protect	2090.00	CY			462	14,984	6,676	37,620	0	59,280	28.36
1.01.02.03. Top Soil											
<02000 0000 Site Work>											
<02800 0000 Landscaping>											
<02820 0000 Top Soil>											
<02820 3000 Furnish And Place Imported Top Soil>											
MIL AA Furn & Pl Im					0.13	4.60	2.86	20.42	0.00	27.89	
ported Topso	150.00	CY	CODLA	11.50	20	690	429	3,063	0	4,183	27.89
il, 6"Dp											
TOTAL Top Soil	150.00	CY			20	690	429	3,063	0	4,183	27.89
TOTAL Backfill	1.00	EA			661	22,028	10,129	62,691	0	94,848	94848.03

1.01.03. Precast Concrete Conduit(6'X12')
Material cost obtained from Retondo concrte co.

<03000 0000 Concrete>

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
<03400 0000 Precast Concrete>											
<Note - Precast Concrete Prices Are Based On A Precast Operation>											
<Producing Large Quantities Of Precast Products. Prices Include>											
<Delivery To Construction Site And Overhead/Mobilization Charges For>											
<The Precast Plant>											
<03413 0000 Precast Structural Sections>											
<03413 1000 Precast Beams, Girder And Joists>											
<03413 1200 Erection Costs Using A 125 Ton Crawler Crane>											
<Note - Erection Costs Include Handling, Hoisting Into Place,>											
<Alignment, Bracing And Permanent Connections. Costs Do Not Include>											
<Grouting Or Caulking Of Joints>											
M MIL AA Erect Prec S					5.00	149.90	125.36	3000.00	0.00	3275.26	
trl Sect,10-	30.00	EA	SIWST	2.00	150	4,497	3,761	90,000	0	98,258	3275.26
15 Tn/Pc											
Bm,Gird,Jst;55'Max Rad,90 Tn Crn											
TOTAL Precast Conc	231.00	LF			150	4,497	3,761	90,000	0	98,258	425.36
1.01.04. Sluice Gate (6'X12')											
USR SS Motor Conver					0.00	0.00	0.00	10000.00	0.00	10000.00	
sion	2.00	EA	N/A	0.00	0	0	0	26,503	0	26,503	13251.41
<05000 0000 Metals>											
<05500 0000 Metal Fabrication>											
<05651 0000 Water Control Devices>											
<05651 1000 Water Control Gates>											
<05651 1100 Heavy Duty Sluice Gates Self Contained>											
<Including Crank Operated Geared Gate Lift, Anchor Bolts, And>											
<Grouting.>											
CIV SS 72"x 72"Heav					186.17	6038.23	1968.55	25782.23	0.00	33789.01	
y Duty Sluic	2.00	EA	SIWSE	0.02	372	16,003	5,217	68,330	0	89,550	44775.20
e Gates											
Self Contained w/Crank Oper Gate											
TOTAL Sluice Gate	2.00	EA			372	16,003	5,217	94,833	0	116,053	58026.61
1.01.05. Stop Log											
TOTAL Waterman Alu	1.00	EA			40	1,200	1,200	22,500	0	24,900	24900.00

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
1.01.05.03. Foundation											
<03000 0000 Concrete>											
<03100 0000 Concrete Formwork>											
<03110 0000 Structural Cast-In-Place Concrete Formwork>											
<Note - Includes Erecting, Stripping, Cleaning, And Stacking Plus> <Accessories>											
<03110 1000 Foundations (Plywood Forms)>											
<03110 1100 Footing Forms>											
<03110 1120 Column Footings (Spread)>											
L MIL AA Clmn Spread					0.20	6.02	0.13	1.09	0.00	7.24	
Footing Form s, 1 Use	20.00	SF	ACARJ	20.00	4	120	3	22	0	145	7.24
Plywd Forms, Form & Strip w/Acc											
<03000 0000 Concrete>											
<03300 0000 Cast-In-Place Concrete>											
<03305 0000 Concrete Curing>											
L MIL AA Conc Curing,					0.66	20.62	0.11	2.91	0.00	23.65	
7.5 Oz Burla p,4 Uses	1.00	CSF	ULABB	3.79	1	21	0	3	0	24	23.65
<03300 0000 Cast-In-Place Concrete>											
<03311 0000 Normal Weight Structural Concrete>											
<03311 1000 Concrete Placement>											
<03311 1100 Place 3000 Psi Concrete FoundaTion By Method> <Indicated>											
<03311 1120 Footing - Continuous>											
B MIL AA Pour Cont Ft					0.50	15.93	5.59	65.00	0.00	86.52	
gs, Shlw, Co nc Pump	1.00	CY	ALABI	16.00	0	16	6	65	0	87	86.52
Place 3000 PSI Conc Foundations											
TOTAL Foundation	1.00	EA			5	157	8	90	0	255	254.87
1.01.05.04. MIsc.											
USR AA Misc.					0.00	0.00	0.00	500.00	0.00	500.00	
	1.00	EA		0.00	0	0	0	500	0	500	500.00
TOTAL MIsc.	1.00	EA			0	0	0	500	0	500	500.00
TOTAL Stop Log	1.00	EA			45	1,357	1,208	23,090	0	25,655	25654.87

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
1.01.06. Remove and Reconst 32'x15' Road											
1.01.06.01. Demolition											
<02000 0000 Site Work>											
<02110 0000 Demolition>											
<02112 0000 Selective Demolition>											
<02112 1000 Miscellaneous Removals>											
<Note - All Items Listed Below Are Priced To Include Machine Break-Up> <And Loading>											
<02112 1100 Remove Paving And Base Course>											
B MIL AA Demo Bitumin					0.20	6.77	1.91	0.00	0.00	8.68	
ous Roads	55.00	SY	CODEF	21.26	11	372	105	0	0	478	8.68
Remove Paving and Base Course											
TOTAL Demolition					11	372	105	0	0	478	
1.01.06.02. Backfill											
<02000 0000 Site Work>											
<02200 0000 Earthwork>											
<02221 0000 Trenching, Backfilling, And Compaction>											
<02221 6000 Spread Dumped Fill Or Gravel W/O Compaction>											
<Note - W/Dozer In An Open Area>											
L MIL AA Sprd Dumped					0.02	0.74	1.23	0.00	0.00	1.96	
Fill/Grvl, 6	55.00	SY	CODTG	62.79	1	40	67	0	0	108	1.96
" Layers Without Compaction											
<02221 0000 Trenching, Backfilling, And Compaction>											
<02221 7000 Compaction In 6 In (15Cm) Layers>											
USR AA Compaction,					0.15	4.69	0.15	12.00	0.00	16.84	
6" Layers w/	10.00	CY	CLACA	33.33	2	47	2	120	0	168	16.84
Air Tamp By Hand, (15cm) Layers											
TOTAL Backfill					3	87	69	120	0	276	
1.01.06.03. Paving											
<02000 0000 Site Work>											
<02600 0000 Paving And Surfacing>											
<02612 0000 Bituminous Concrete Paving>											
<02612 1400 Surface Courses>											

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
B MIL AA Bituminous H					0.48	15.61	6.03	24.98	0.00	46.61	
ot Mix Surf	10.00	TON	XASPA	25.00	5	156	60	250	0	466	46.61
Course											
3774#/CY (2242Kg/M3),Ctrl Plant											
TOTAL Paving					5	156	60	250	0	466	
TOTAL Remove and R	1.00	EA			18	616	235	370	0	1,220	1220.07
1.01.07. Remove and Reconst 70'x25' Road											
1.01.07.01. Demolition											
<02000 0000 Site Work>											
<02600 0000 Paving And Surfacing>											
<02612 0000 Bituminous Concrete Paving>											
<02612 1400 Surface Courses>											
<02112 1100 Remove Paving And Base Course>											
USR AA Demo Bitumin					0.28	9.48	2.68	0.00	0.00	12.16	
ous Roads	195.00	SY	CODEF	15.18	55	1,848	523	0	0	2,371	12.16
Remove Paving and Base Course											
TOTAL Demolition					55	1,848	523	0	0	2,371	
1.01.07.02. Backfill											
<02000 0000 Site Work>											
<02200 0000 Earthwork>											
<02221 0000 Trenching, Backfilling, And Compaction>											
<02221 6000 Spread Dumped Fill Or Gravel W/O Compaction>											
<Note - W/Dozer In An Open Area>											
L MIL AA Sprd Dumped					0.01	0.37	0.61	0.00	0.00	0.98	
Fill/Grvl, 6	195.00	SY	CODTG	125.58	2	72	120	0	0	191	0.98
" Layers											
Without Compaction											
<02221 0000 Trenching, Backfilling, And Compaction>											
<02221 7000 Compaction In 6 In (15Cm) Layers>											
USR AA Compaction,					0.20	6.25	0.20	12.00	0.00	18.45	
6" Layers W/	35.00	CY	CLACA	25.00	7	219	7	420	0	646	18.45
Air Tamp											
By Hand, (15cm) Layers											
TOTAL Backfill					9	290	127	420	0	837	

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
1.01.07.03. Paving											
<02000 0000 Site Work>											
<02600 0000 Paving And Surfacing>											
<02612 0000 Bituminous Concrete Paving>											
<02612 1400 Surface Courses>											
B MIL AA Bituminous H					0.48	15.61	6.03	24.98	0.00	46.61	
ot Mix Surf	30.00	TON	XASPA	25.00	14	468	181	749	0	1,398	46.61
Course											
3774#/CY (2242Kg/M3),Ctrl Plant											
TOTAL Paving					14	468	181	749	0	1,398	
TOTAL Remove and R	1.00	EA			78	2,607	830	1,169	0	4,606	4606.33
1.01.08. Remove and Replace Guide Rail											
1.01.08.01. Remove Guide Rail											
<02000 0000 Site Work>											
<02110 0000 Demolition>											
<02112 0000 Selective Demolition>											
<02112 5000 Fence Removals>											
<02112 5000 Fence Removals - Chain Link and Barbed Wire>											
L CIV AA Demo Guardra					0.20	6.26	0.26	0.00	0.00	6.52	
il	200.00	LF	ULABK	15.00	40	1,253	51	0	0	1,304	6.52
TOTAL Remove Guide	200.00	LF			40	1,253	51	0	0	1,304	6.52
1.01.08.02. Replace Guide Rail											
USR AA Fiber Optic					0.29	8.93	0.07	5.00	0.00	14.00	
	200.00	LF	ULABH	17.50	57	1,786	14	1,000	0	2,799	14.00
<02000 0000 Site Work>											
<02700 0000 Site Improvements>											
<02721 0000 Guard Rails>											
<02721 3000 Cable Guard Rail, 3 At 3/4 In Cables>											
MIL AA Cable Guard					0.11	3.52	0.03	9.08	0.00	12.63	
Rail Steel P	200.00	LF	ULABH	44.38	23	704	5	1,816	0	2,526	12.63
ost											
3 Cables @ 3/4" Diameter											
TOTAL Replace Guid	200.00	LF			80	2,490	19	2,816	0	5,325	26.62

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
TOTAL Remove and R	200.00	LF			120	3,742	70	2,816	0	6,629	33.14

1.01.09. Wing Walls

<03000 0000 Concrete>
<03100 0000 Concrete Formwork>
<03110 0000 Structural Cast-In-Place Concrete Formwork>
<Note - Includes Erecting, Stripping, Cleaning, And Stacking Plus>
<Accessories>
<03110 1000 Foundations (Plywood Forms)>
<03110 1400 Wall Forms (Below Grade)>
<03110 1430 Retaining Wall>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
M MIL AA Retaining Wa					0.16	4.62	0.11	2.70	0.00	7.43	
ll Forms,0-8	800.00	SF	ACARL	31.25	128	3,697	84	2,160	0	5,941	7.43
', 1 Use											
(Below Gr) Plywd Forms,F&S w/Acc											

<03000 0000 Concrete>
<03200 0000 Concrete Reinforcement>
<03210 0000 Reinforcing Steel>
<03210 2000 Beams, Columns And Walls>
<03210 2000 Basic Cost Items>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
M MIL AA Gr 60 Restee					11.43	295.83	3.05	575.00	0.00	873.88	
l,Bm,Clmn,Wa	1.00	TON	SIWRC	0.35	11	296	3	575	0	874	873.88
ll,#7-Up											

<03000 0000 Concrete>
<03300 0000 Cast-In-Place Concrete>
<03305 0000 Concrete Curing>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
MIL AA Conc Curing,					0.21	6.58	0.04	4.15	0.00	10.76	
Sprayed Mem	8.00	CSF	ULABB	11.88	2	53	0	33	0	86	10.76
brane											
Curing Compound											

<03300 0000 Cast-In-Place Concrete>
<03311 0000 Normal Weight Structural Concrete>
<03311 1000 Concrete Placement>
<03311 1200 Superstructure Placed As Indicated>
<03311 1240 Walls>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
B MIL AA Pour Conc Wa					0.96	30.40	8.71	70.00	0.00	109.11	
ll,15"Tk,Cra	65.00	CY	ALABG	9.38	62	1,976	566	4,550	0	7,092	109.11
ne & Bkt											
(38cm) 3000 PSI Conc											

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
TOTAL Wing Walls	3.00	EA			204	6,022	654	7,318	0	13,993	4664.48
1.01.10. Remove and Replace Wood Rail											
1.01.10.01. Remove Wood Rail											
<02000 0000 Site Work>											
<02110 0000 Demolition>											
<02112 0000 Selective Demolition>											
<02112 5000 Fence Removals>											
<02112 5000 Fence Removals - Chain Link and Barbed Wire>											
L CIV AA Demo Woodrai					0.20	6.26	0.26	0.00	0.00	6.52	
l	200.00	LF	ULABK	15.00	40	1,253	51	0	0	1,304	6.52
TOTAL Remove Wood	200.00	LF			40	1,253	51	0	0	1,304	6.52
1.01.10.02. Replace Wood Rail											
<02000 0000 Site Work>											
<02700 0000 Site Improvements>											
<02713 0000 Wooden Fences>											
<02713 2000 Board Fence,1X4In Boards, 2X4In Rails,4X4In> <Post>											
CIV AA Board Fence,					0.20	5.99	0.09	3.97	0.00	10.06	
2-2"x 4" Ra	200.00	LF	XLABC	16.88	40	1,199	19	794	0	2,011	10.06
ils 4'H											
1"x 4" Boards, Preserv Treated											
<02700 0000 Site Improvements>											
<02721 0000 Guard Rails>											
<02721 3000 Cable Guard Rail, 3 At 3/4 In Cables>											
MIL AA Cable Guard					0.10	3.20	0.02	12.31	0.00	15.54	
Rail Wood Po	200.00	LF	ULABH	48.75	21	641	5	2,462	0	3,108	15.54
st											
3 Cables @ 3/4" Diameter											
TOTAL Replace Wood	200.00	LF			60	1,840	24	3,256	0	5,119	25.60
TOTAL Remove and R	200.00	LF			100	3,092	75	3,256	0	6,423	32.12

1.01. Scheme 5 - (6'x	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST

1.01.11. Sheetpiles

<02000 0000 Site Work>
<02400 0000 Shoring>
<02411 0000 Steel Sheeting>
<02411 1000 Standard Carbon Grade Steel Sheeting - Pull And>
<Salvage>
<02411 1000 Basic Cost Items>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
MIL AA Shoring for					9.70	311.90	228.68	703.58	0.00	1244.16	
25'(8M) Exc,	66.00	TON	CPIDV	0.83	640	20,585	15,093	46,436	0	82,115	1244.16
38 PSF											
Steel Sheeting, Pull and Salvage											
TOTAL Sheetpiles	3500.00	SF			640	20,585	15,093	46,436	0	82,115	23.46

1.01.12. Constr.Remove Temp.Channel Cross

<02000 0000 Site Work>
<02200 0000 Earthwork>
<02221 0000 Trenching, Backfilling, And Compaction>
<02221 6000 Spread Dumped Fill Or Gravel W/O Compaction>
<Note - W/Dozer In An Open Area>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
M AF AA Spread Borro					0.01	0.51	0.58	0.00	0.00	1.09	
w W/Dozer	750.00	CY	CODTE	90.00	10	385	434	0	0	819	1.09

<02000 0000 Site Work>
<02450 0000 Utility Pipelines>
<02458 0000 Corrugated Metal Pipe>
<02458 1000 Galv, Or Aluminum, Bituminous Coated With Paved>
<Invert, 20 To 30 Ft Lengths>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
M MIL AA 48"(122cm) 1					0.48	15.45	2.91	36.65	0.00	55.01	
6 Ga Corr Me	65.00	LF	UOEHC	12.50	31	1,004	189	2,382	0	3,575	55.01
tal Pipe											
Galv Or Alum, Bituminous Coated											

<02000 0000 Site Work>
<02700 0000 Site Improvements>
<02721 0000 Guard Rails>
<02721 9000 Median Barrier, Concrete>

Description	QUANTY	UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
CIV AA Median Barri					0.14	4.56	1.31	24.05	0.00	29.92	
er, Slipform	160.00	LF	ALABG	62.50	23	730	209	3,848	0	4,787	29.92
ed Conc											

1.01. Scheme 5 - (6'x	QUANTY UOM	CREW ID	OUTPUT	MANHOUR	LABOR	EQUIPMNT	MATERIAL	SUBCONTR	TOTAL COST	UNIT COST
TOTAL Constr.Remov				65	2,119	832	6,230	0	9,181	
1.01.13. Constr.Remove Temp.Gravel Rd.										
<02000 0000 Site Work>										
<02600 0000 Paving And Surfacing>										
<02619 0000 Gravel Surfacing>										
M MIL AA Gravel Surfa				0.11	3.65	1.89	15.79	0.00	21.33	
cing, Delive red	350.00 CY	COFGA	18.75	37	1,279	660	5,527	0	7,465	21.33
TOTAL Constr.Remov				37	1,279	660	5,527	0	7,465	
TOTAL Scheme 5 - (				3,244	108,884	58,981	343,736	0	511,602	
TOTAL SAGAMORE MAR	1.00 EA			3,244	108,884	58,981	343,736	0	511,602	511601.70
TOTAL SAGAMORE MAR	1.00 EA			3,244	108,884	58,981	343,736	0	511,602	511601.70

ITEM ID	DESCRIPTION				
0.01. 0. Overhead Items - AA					
0.01.01. Tide Gate Sub					
0.01.02. Sluice Gate					
1.01.01. Excavation					
CODEA	1 B-eqoprcrn + 1 1 Cy Hydr. Excavator	PROD =	100%	CREW HOURS =	278
COEID	1 B-trkdvrhv + 1 12 Cy Dump Truck	PROD =	100%	CREW HOURS =	198
1.01.02. Backfill					
CODLA	1 B-eqoprmed + 1 1.5 Cy Front End Ldr, Wheel	PROD =	100%	CREW HOURS =	13
CODTA	1 B-eqoprmed + 1 Dozer, Cat D-3C, 65 Hp	PROD =	100%	CREW HOURS =	105
CODTE	1 B-eqoprmed + 1 Dozer, Cat D-6H, 165 Hp	PROD =	100%	CREW HOURS =	17
COETF	2 B-laborer + 1 8 Cy Dump Truck,Bckhoe/Loadr	PROD =	100%	CREW HOURS =	116
1.01.03. Precast Concrete Conduit(6'X12')					
SIWST	7 B-strsteel + 1 240 Ton Crane, Cwlr	PROD =	100%	CREW HOURS =	15
1.01.04. Sluice Gate (6'X12')					
SIWSE	2 B-strsteel + 1 20 Ton Crane, Hydraulic R/T	PROD =	100%	CREW HOURS =	106
1.01.05. Stop Log					
ACARJ	3 B-carpntr/labr(semi-skld) + MiscPowrTools	PROD =	100%	CREW HOURS =	1
ALABI	6 B-laborer + 117 Cy/hr Conc Pump Truck	PROD =	100%	CREW HOURS =	0
ULABB	2 B-laborer + Small Tools	PROD =	100%	CREW HOURS =	0
1.01.06. Remove and Reconst 32'x15' Road					
CLACA	5 B-laborer + 2 Hand Compaction Rammer	PROD =	100%	CREW HOURS =	0
CODEF	2 B-laborer + 2 Loadr-Bckhoe/Compctr	PROD =	100%	CREW HOURS =	3
CODTG	1 B-eqoprmed + 1 Dozer, Cat D-7H, 215 Hp	PROD =	100%	CREW HOURS =	1
* XASPA	7 X-laborer + 1 Asphalt Paving Machine	PROD =	100%	CREW HOURS =	0
1.01.07. Remove and Reconst 70'x25' Road					
CLACA	5 B-laborer + 2 Hand Compaction Rammer	PROD =	100%	CREW HOURS =	1
CODEF	2 B-laborer + 2 Loadr-Bckhoe/Compctr	PROD =	100%	CREW HOURS =	13
CODTG	1 B-eqoprmed + 1 Dozer, Cat D-7H, 215 Hp	PROD =	100%	CREW HOURS =	2
* XASPA	7 X-laborer + 1 Asphalt Paving Machine	PROD =	100%	CREW HOURS =	1
1.01.08. Remove and Replace Guide Rail					
ULABH	5 B-laborer + Small Tools	PROD =	100%	CREW HOURS =	16
ULABK	3 B-laborer + 1 3 Ton Flatbed Truck	PROD =	100%	CREW HOURS =	13
1.01.09. Wing Walls					
ACARL	4 B-carpntr/labr(semi-skld) + MiscPowrTools	PROD =	100%	CREW HOURS =	26
ALABG	6 B-laborer + 1 60 Ton Crane/2 Conc Vibrators	PROD =	100%	CREW HOURS =	7
SIWRC	3 B-rodman + Small Tools	PROD =	100%	CREW HOURS =	3
ULABB	2 B-laborer + Small Tools	PROD =	100%	CREW HOURS =	1
1.01.10. Remove and Replace Wood Rail					
ULABH	5 B-laborer + Small Tools	PROD =	100%	CREW HOURS =	4
ULABK	3 B-laborer + 1 3 Ton Flatbed Truck	PROD =	100%	CREW HOURS =	13
XLABC	3 X-laborer + Small Tools	PROD =	100%	CREW HOURS =	12

ITEM ID	DESCRIPTION				
1.01.11. Sheetpiles					
CPIDV	5 B-piledrvr + 1 Vibratory Pile Hammer/40T Crane	PROD =	100%	CREW HOURS =	80
1.01.12. Constr.Remove Temp.Channel Cross					
ALABG	6 B-laborer + 1 60 Ton Crane/2 Conc Vibrators	PROD =	100%	CREW HOURS =	3
CODTE	1 B-eqoprmed + 1 Dozer, Cat D-6H, 165 Hp	PROD =	100%	CREW HOURS =	8
UOEHC	5 B-laborer + 1 20 Ton Crane, Hydraulic R/T	PROD =	100%	CREW HOURS =	5
1.01.13. Constr.Remove Temp.Gravel Rd.					
COFGA	1 B-eqoprmed + 1 Grader 12-G	PROD =	100%	CREW HOURS =	19

APPENDIX H

REAL ESTATE REQUIREMENTS

PURPOSE

The purpose of this report is to estimate the preliminary real estate costs associated with the restoration of salt marsh and estuarine habitat in Sagamore Marsh, located in Bourne and Sandwich, Massachusetts.

This preliminary report was written in accordance to Regulation No. ECll05-2-l00, Chapter 3, Section IV, PROJECT MODIFICATIONS FOR IMPROVEMENT OF THE ENVIRONMENT.

SCOPE

The scope of this Real Estate Planning report consisted of identifying the ownership, size, assessed value, and zoning of all parcels within and adjacent to Sagamore Marsh.

INSPECTION OF REAL ESTATE

Properties within and adjacent to Sagamore Marsh were viewed on aerial photos and town tax maps; and the ownership, development status, and value of the parcels was discussed with local officials in October and November l995.

DESCRIPTION OF PROJECT AREA

Sagamore Marsh is located in the towns of Bourne and Sandwich, Barnstable County, in eastern Massachusetts. Sagamore Marsh lies on the north side of the Cape Cod Canal, at the Canal's east end. The area of Sagamore Marsh studied for restoration consisted of the unfilled area which existed as salt marsh and estuarine habitat prior to the reduction of tidal flows in the mid-1930's. The area is approximately 185 acres. The area is bounded on the south by the Cape Cod Canal, Sagamore Hill, and the filled area to the north of Scusset Beach State Park; on the east by residential properties; on the north by Pilgrim Road and residential properties; and on the west by residential properties. See attached Exhibit "A" in addenda of this report.

PROPOSED PROJECT MODIFICATION

The recommended alternative is to replace the existing 48-inch diameter culverts beneath the Canal Service Road and Scusset Beach Road with 6-foot high by 12-foot wide culvert openings, install stop logs on the Canal-side of the Canal Service Road culvert and electric sluice gates on the marsh-side of the Canal Service Road culvert for flow control, widen the existing 210-foot long man-made channel between the roads and the 600-foot long man-made channel upstream of Scusset Beach Road from an existing bottom width of 4 feet to a bottom width of 12 feet by excavating the east channel bank at a slope of l-foot vertical to 2 feet horizontal and leaving the west channel bank undisturbed wherever possible, deepen the man-made channel between the roads to remove siltation, and deepen the man-made channel upstream of Scusset Beach Road as required to maintain a constant channel slope from the Scusset Beach Road culvert to the end of the man-made section. This alternative will increase high tide elevations in the middle of the marsh 0.1 to 0.5 feet (about 1-6 inches), and is estimated to restore approximately 50 acres of salt marsh.

AFFECT OF RESTORATION ON PROPERTIES

Introduction

The feasibility study determined that the one-year storm water elevation will be approximately 3.7 feet NGVD[1]. Only lands below that elevation will be affected by the restoration.

Based on cursory review of aerial photos and topographic mapping and on inspections of the area, most areas below elevation 6 feet NGVD are wetland - either fresh water or salt marsh. Fresh water wetlands, which are supported from seeps, springs, and runoff exist around the perimeter of the marsh. Some areas on the perimeter of the marsh which are currently fresh water wetland will be converted to brackish water wetlands or salt marsh as the salinity is increased. Existing wetlands which are expected to be changed from fresh water wetlands to brackish water wetlands or salt marsh will not be acquired in fee, since there will be no impact to the owner's use or the development potential of the parcel.

Developed Parcels

The first floor elevation of every house and the low point in the yard in the rear of the house was surveyed for every house adjacent to the marsh below elevation 10 feet NGVD. The elevations are shown in Appendix A of the Main Report, "Topographic Survey". Only one house (244 Phillips Road, Sandwich Map 96 Parcel 67) had a low point in the rear yard below elevation 3.7 feet NGVD, but the low point was beyond the property line. This will be verified during the development of plans and specifications. Houses on the west side of the marsh were not surveyed because they are on high ground, but the topographic mapping shows that a small portion of one parcel (5 Vineyard Circle, Bourne Map 7.4 Parcel 21) at the rear of the property may be below elevation 3.7 feet NGVD, although it appears that all land below elevation 6 feet NGVD is wetland. There were no other houses or yards below elevation 3.7 feet NGVD. Therefore it appears that no developed parcels of land will be affected by the recommended plan. If it is found during the development of plans and specifications that any non-wetland portion of either of the two developed parcels will be affected, then either: 1) the project will be modified to eliminate that impact, 2) other remedial action will be taken to prevent the impact, or 3) a real estate interest will be acquired over that portion by the non-Federal sponsor.

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[1]National Geodetic Vertical Datum of 1929, a reference datum.

Undeveloped Parcels

There was no detailed topographic survey performed of every undeveloped parcel within and adjacent to the marsh.

A review of undeveloped parcels within and adjacent to the marsh found that only existing wetlands will be affected by the proposed project. No lands which are currently non-wetland are expected to be changed to wetland by this project. As stated previously, existing wetlands which are expected to be changed from fresh water wetlands to brackish water wetlands or salt marsh will not be purchased in fee, since there is no impact to the owner's use or the development potential of the parcel.

There are 51 undeveloped parcels of land within and adjacent to the marsh which may have some or all of the parcel affected by marsh restoration. The parcels are listed by ownership in Table 1. See attached Table 1 in addenda of this report. All of the land expected to be affected is existing wetland. Therefore, no undeveloped parcels of land are expected to be acquired in fee.

Prior to the development of plans and specifications, at the request of owners of undeveloped parcels listed in Appendix H, and with the consent of abutting property owners, the Commonwealth shall arrange for the delineation of wetland areas on the undeveloped parcels. If necessary, wetlands will be delineated and the parcels will be surveyed as needed to determine the location of the wetland line in relation to elevation 3.7 feet NGVD. If it is found that non-wetland areas lie below elevation 3.7 feet NGVD then either: 1) the project will be modified to eliminate the impact, 2) other remedial action will be taken to prevent the impact, or 3) a real estate interest will be acquired over that portion by the non-federal sponsor.

GOVERNMENT OWNED FACILITIES

Section III of the Act of Congress approved 8 July 1958, (PL 85-500) authorized the protection, realteration, reconstruction, relocation or replacement of municipally-owned facilities. A preliminary inspection of the project areas indicated that no government-owned facilities will be affected by the proposed restoration.

RIGHTS TO BE ACQUIRED

Permanent Easement Areas

There are no permanent easement areas expected to be acquired at this time. This will be confirmed during the development of plans and specifications.

Temporary Construction Easements

A temporary construction easement area of 9.7 acres will be required for construction of the proposed project modifications, for temporary relocation of Scusset Beach Road and the Canal Service Road around the proposed construction, and for staging and stockpile areas. The temporary construction easement area was conservatively sized, and it is expected that the temporary construction easement area will be reduced in size during the development of plans and specifications. Construction is expected to be completed in nine months, but the temporary construction easement will be acquired for one year.

There are 3 parcels of land affected by the temporary construction easement. The parcels are under ownership of the United States of America, the Town of Bourne and the Commonwealth of Massachusetts. Therefore, no temporary easement costs are required. See attached Exhibit "B" in addenda of this report.

	Parcels of Land	Acreage
	1 U.S. of America	9.02
	1 Commonwealth	0.44
	1 Town of Bourne	0.24
Total	3 Parcels	9.70 Acres

ACQUISITION COSTS

Acquisition costs include costs for mapping, surveying, preparing legal descriptions, title evidence, appraisals, negotiations, and closing and administrative costs for possible condemnations. Since no lands are to be acquired, there are no acquisition costs involved.

RELOCATION COSTS

Public law 91-646, Uniform Relocations Assistance Act of 1970, provided for uniform and equitable treatment of persons displaced from their homes, businesses, or farms by a Federally Assisted Program. It also established uniform and equitable land acquisitions policies for these projects. Included among the items under PL 91-646 are the following:

a. Moving Expenses

b. Relocation Allowance (Business)

c. Replacement Housing (Tenants)

d. Relocation Advisory Services

e. Recording Fees

f. Transfer Taxes

g. Mortgage Prepayment Costs

h. Real Estate Tax Refunds

Preliminary investigations indicate that relocation will not be required. Should the existing preliminary taking lines be changed to include improvements, then the taking authority must certify that there will be available, in areas generally not less desirable and at rents or prices within the financial means of displaced persons, decent and safe sanitary facilities available to such displaced persons who require such dwellings and reasonably accessible to their places of employment.

RELOCATION ASSISTANCE COSTS

None required.

SEVERANCE DAMAGES

Severance damages usually occur when partial takings are acquired which restrict the remaining portion from full economic development. The severance damages are measured and estimated on the basis of a "Before" and "After" appraisal method and will reflect actual value loss incurred to the remainder as a result of partial acquisition. Detailed appraisals will reflect these losses.

No damage to any properties within or adjacent to Sagamore Marsh will be caused by this project. The high tide will be increased by 0.1 to 0.5 feet in the middle of the marsh.

Preliminary investigations indicate that none of the ownerships will incur severance damage due to the proposed project. The ownerships will remain conforming to existing zoning requirements. If any of the taking lines change from the preliminary investigation, severance damages will be re-evaluated.

PROTECTION AND ENHANCEMENT OF CULTURAL ENVIRONMENT

In accordance with instruction set forth in teletype DA (DAEN) R191306A, dated October 1971, Subject: "E011593, 13 May 1971, Protection and Enhancement of Cultural Environment, " a study has been made in the subject areas. The study revealed that no local, State, Federally owned nor Federally controlled property of historical significance would fall within the provisions of EOl1593.

CONTINGENCIES

A contingency allowance of 25 percent is considered to be reasonably adequate to provide for possible appreciation of property values from the time of this estimate to the acquisition date, for possible minor property line adjustments, or for additional ownerships which may be developed by refinement to taking lines, for adverse condemnation awards, and to allow for practical and realistic negotiations.

EVALUATION AND CONCLUSION

A careful and thorough search of the Town of Bourne and Sandwich's real estate records was made and knowledgeable officials of the Town of Bourne and Sandwich were interviewed.

The preliminary investigations indicate that the tidal flushing will increase the water level at high tide by 0.1 to 0.5 feet. Properties within and adjacent to Sagamore Marsh will not be adversely affected by the proposed project. However, if this information should change, real estate requirements will be re-evaluated.

The temporary construction easement of 9.7 acres is required for approximately one year. Scussett Beach Road and the Cape Cod Canal Service Road will be temporarily relocated around the construction area. Also, storage of equipment and stock piling of material is required is required on a temporary basis.

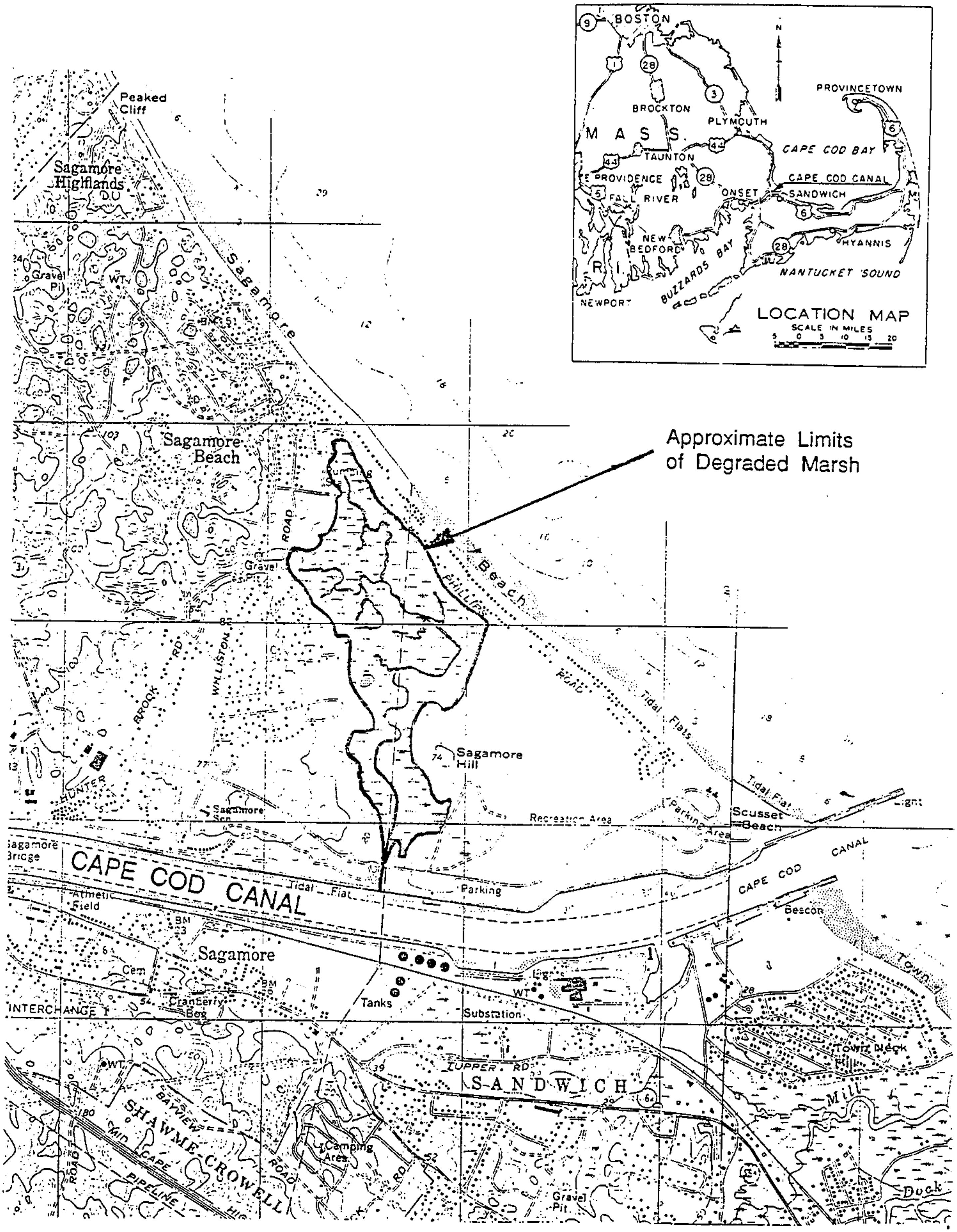
No lands are to be acquired for this project. Following is the summary of real estate costs attributable to this project:

SUMMARY OF REAL ESTATE COSTS

The following is an estimate of the real estate costs for the interests being acquired for the Sagamore Marsh Restoration Project.

Fee Acquisition	-0-	
Permanent Easement	-0-	
Temporary Construction Easement	-0-	
Total	$ -0-	
Contingency - 25% of Above		$ -0-
Subtotal	$ -0-	
Acquisition Costs	$ -0-	
Relocation Assistance Costs	$ -0-	
Severance Damages	$ -0-	
Total Estimated Real Estate Costs	$ -0-	

ADDENDA



Sagamore Marsh Restoration

EXHIBIT "A"

EXHIBIT "B"

SAGAMORE MARSH RESTORATION FEASIBILITY STUDY

Required Temporary Construction Easements

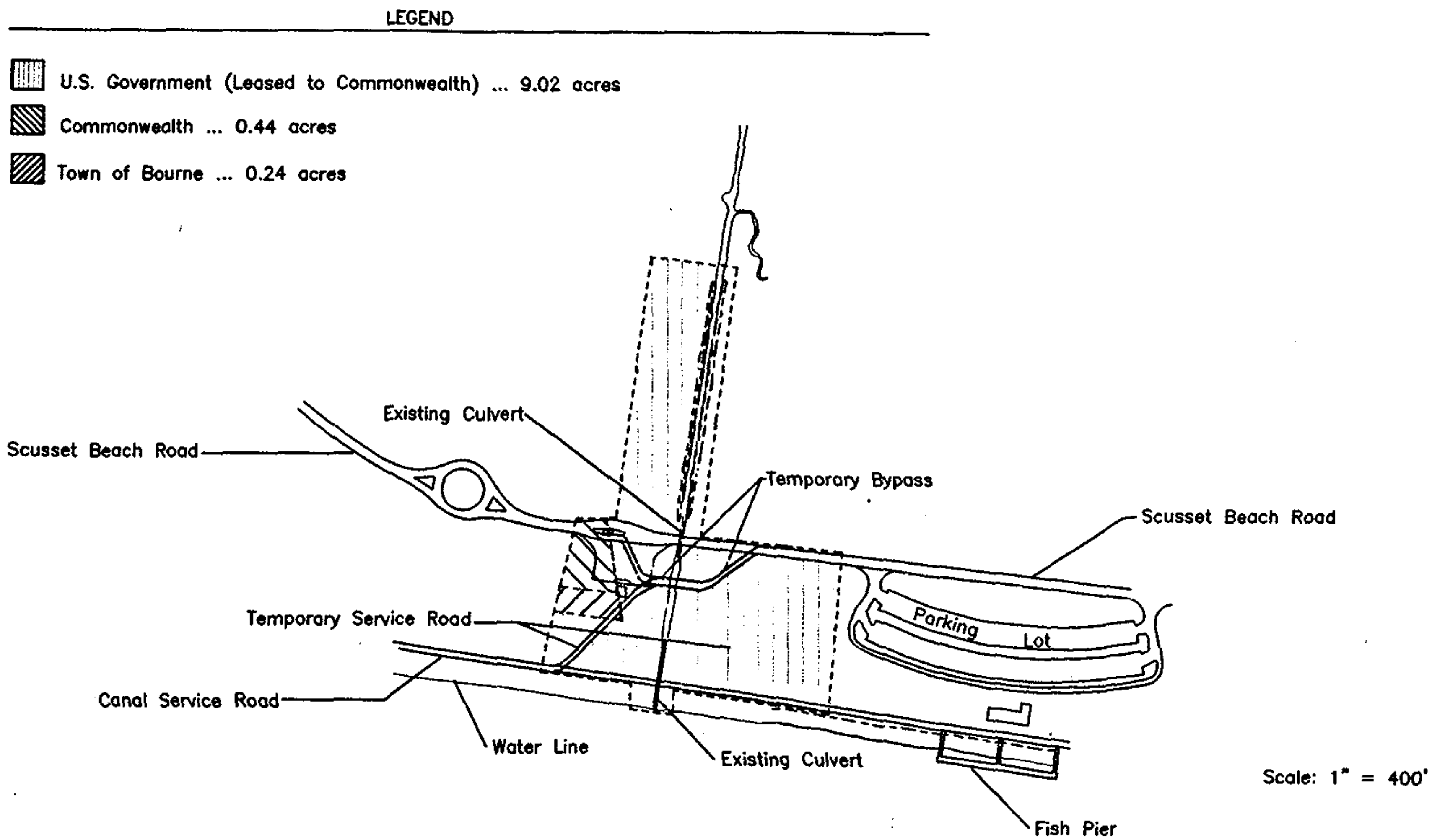


Table 1. Undeveloped Parcels within and adjacent to Sagamore Marsh.				
				Total
Owner	Location	Map/Parcel	Street Address	Acreage
U.S. Government	Sandwich	44/1	None	325.0
		44/2		0.94
	Total Acreage, U.S.Government:			325.9
Commonwealth	Bourne	12/1	None	80.0
	Total Acreage, Commonwealth:			80.0
Town of Bourne	Bourne	7.0/51	None	16.50
		7.2/41	None	0.62
		7.2/42	None	0.40
		7.2/43	None	0.25
		7.2/44	None	0.27
		7.2/45	None	0.25
		7.2/46	None	0.23
		7.2/47	None	0.23
		7.2/48	None	0.23
		7.2/49	None	0.24
		7.2/50	None	0.34
		7.2/52	None	9.64
	Total Acreage, Town of Bourne:			29.2
Town of Sandwich	Sandwich	46/2	None	20.0
		46/3	None	2.35
		46/4	None	0.66
		46/5	None	1.46
		46/6	None	20.7
		46/7	None	29.85
		96/86	None	2.35
	Total Acreage, Town of Sandwich:			77.4

Table 1. Undeveloped Parcels within and adjacent to Sagamore Marsh (continued).				
Owner	Location	Map/Parcel	Street Address	Total Acreage
Private	Bourne	4.4/132.3	None	0.81
		4.4/132.4	None	0.95
		4.4/134 *	182 Phillips	0.14
		4.4/139 *	158 Phillips	0.14
		7.0/48	None	13.58
		7.0/49	None	34.93
		7.0/50 *	None	7.55
		7.2/51	None	9.80
		7.2/55 *	196 Phillips	0.14
		7.4/10	29 Marsh Pond	0.61
	Sandwich	46/8	None	4.27
		46/9 *	None	4.70
		46/10	None	1.00
		95/54	344 Phillips	0.29
		95/58	None	0.22
		95/61	330 Phillips	0.16
		95/63	None	0.16
		95/64	None	0.37
		96/61	None	0.21
		96/66	246 Phillips	0.21
		96/68	None	0.21
		96/70	None	0.21
		96/73	232 Phillips	0.21
		96/76	224 Phillips	0.11
		96/77	224 Phillips	0.12
		96/79	216 Phillips	0.20
		96/80	214 Phillips	0.13
		97/1	None	0.27
	Total Acreage, Private:			**13.1**
Private Non-Profit	Bourne	7.2/53	None	3.1
	Total Acreage, Private Non-Profit:			**3.1**
	Total Acreage, All:			**515.6**
* Parcel is zoned undevelopable.				

APPENDIX I

PERTINENT CORRESPONDENCE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02254-9149

REPLY TO
ATTENTION OF

August 22, 1996

Planning Directorate
Evaluation Division

RECEIVED
AUG 26 1996
MASS. HIST. COMM.

Ms. Judith McDonough - Executive Director
Massachusetts Historical Commission
The Massachusetts State Archives Building
220 Morrissey Boulevard
Boston, MA 02125

Dear Ms. McDonough:

The U.S. Army Corps of Engineers, New England Division (NED), is in the process of completing the Feasibility Study for Saltmarsh Restoration at the Sagamore Marsh project area in Bourne and Sandwich, Massachusetts. Enclosed for your review is a copy of the final report for the study which includes an Environmental Assessment and an assessment of cultural resources within the project area.

Also enclosed for your information is a copy of Constance Crosby's correspondence, dated November 14, 1994, to Karen Kirk Adams of NED's Regulatory Division concerning Ms. Crosby's review of the subject environmental notification form and a copy of NED's December 14, 1994 letter of coordination concerning cultural resources impacts. To date, a letter of response has not reached our office. We would like to reiterate that the proposed project will have no effect upon significant cultural resources. Several archaeological sites discovered during the Corps' Archaeological Reconnaissance Survey of the Cape Cod Canal completed in September 1994 and located on Sagamore Hill, in particular Sagamore Hill Locuses 1 and 2, are located outside of the proposed study implementation areas as indicated within the report.

Therefore, we feel that the proposed Sagamore Marsh Salt Marsh Restoration study will have no effect upon any structure or site of historic, architectural or archaeological significance as defined by the National Historic Preservation Act of 1966, as amended. We would appreciate your concurrence with this determination and a letter of response so that we may finalize implementation of the project.

If you have any questions, please contact Mr. Marc Paiva, project archaeologist, of the Evaluation Division at (617) 647-8796.

Sincerely,

Joseph L. Ignazio

Joseph L. Ignazio
Director of Planning

Enclosures

CONCURRENCE: Judith B. McDonough

JUDITH B. McDONOUGH 10/1/96
STATE HISTORIC
PRESERVATION OFFICER
MASSACHUSETTS
HISTORICAL COMMISSION

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, Boston, 02202

WILLIAM F. WELD
GOVERNOR
ARGEO PAUL CELLUCCI
LIEUTENANT GOVERNOR
TRUDY COXE
SECRETARY

Tel: (617) 727-9800
Fax: (617) 727-2754

June 5, 1996

Colonel Earle C. Richardson, Division Engineer
Army Corps of Engineers, New England Division
424 Trapelo Road
Waltham, MA 02154-9149

RE: Sagamore Marsh Restoration Project

Dear Colonel Richardson:

The Executive Office of Environmental Affairs, through the Wetlands Restoration & Banking Program, has reviewed the draft Project Modification Report/Environmental Assessment (DPMR/EA) for the Sagamore Marsh Restoration Project and Joseph Ignazio's letter of May 16, 1996, responding to EOEA comments on the DPMR/EA. At this time, all of our outstanding questions have been answered, or a mechanism has been established to ensure that they will be addressed before project construction proceeds (e.g., more precise location of the four-toed salamander population and discrepancies in the 100-year flood elevation between the Army Corps and FEMA). Based on that review, EOEA agrees that the 6'H x 12'W culvert alternative described in the DPMR/EA is the preferred alternative.

Concurrently, the project has been under review by our MEPA Unit. Based on MEPA review, I have determined that the Army Corps has adequately documented its selection of the preferred alternative so that it may proceed with final analysis for that alternative.

A draft Project Cooperation Agreement (PCA) has been negotiated, with all issues raised by EOEA having been satisfactorily addressed at this time. Although the Commonwealth has every expectation of moving forward with this project, as with the Government, the Commonwealth will execute the PCA subject to availability of funds. Furthermore, should the final cost exceed 10% over the current project cost estimate of $1.4 million, the Commonwealth reserves the right to reevaluate the project to determine if sufficient funds are available.

I hereby request that the Army Corps initiate the development of plans and specifications so that we may proceed without delay with this important Coastal America project.

Cordially,

Trudy Coxe

c.c. Commissioner Peter Webber, DEM
Peg Brady, Director, CZM
Christy Foote-Smith, Director, WRBP

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, Boston, 02202

WILLIAM F. WELD
GOVERNOR
ARGEO PAUL CELLUCCI
LIEUTENANT GOVERNOR
TRUDY COXE
SECRETARY

May 31, 1996

Tel: (617) 727-9800
Fax: (617) 727-2754

CERTIFICATE OF THE SECRETARY OF ENVIRONMENTAL AFFAIRS
ON THE
DRAFT ENVIRONMENTAL IMPACT REPORT

PROJECT NAME	: Sagamore Marsh Restoration
PROJECT LOCATION	: Bourne/Sandwich
EOEA NUMBER	: 10174
PROJECT PROPONENT	: EOEA/Wetlands Banking & Restoration Program, Department of Environmental Management & U.S. Army Corps of Engineers
DATE NOTICED IN MONITOR	: April 24, 1996

The Secretary of Environmental Affairs hereby determines that the Draft Environmental Impact Report (DEIR) submitted on the above project adequately and properly complies with the Massachusetts Environmental Policy Act (M.G.L. c. 30, ss. 61-62H) and with its implementing regulations (301 CMR 11.00).

The purpose of the project is to increase the amount of salt water entering the 250 acre Sagamore Marsh (of the 320 acre project site) during tidal cycles in order to re-establish salt marsh vegetation and habitat in some of the existing common reed marsh. The project consists of replacing the 48-inch culverts at the Cape Cod Canal Service Road and Scusset State Beach Reservation Road with 6-foot by 12-foot reinforced concrete box culverts under the roadways. The Canal Service Road culvert will include electric sluice gates and backup stop logs to control tidal flows. In addition, about 1100 linear feet of the existing man-made channel, between the roads and extending into the marsh, will be deepened by removal of silt and the base will be widened from 4 to 12 feet.

The project is before MEPA because it is a state agency project which could alter more than an acre of salt marsh, or more than ten acres of other wetlands resource areas. A Chapter 91 License and a Section 401 Certificate is required from the Department of Environmental Protection (DEP) and a consistency determination must be obtained from the Coastal Zone Management Program (CZM).

The project is being developed by the Executive Office of Environmental Affairs, Wetlands Restoration and Banking Program (WR&BP), with the United States Army Corps of Engineers (COE). The DEIR includes the federal Environmental Assessment and Finding of No Significant Impact documents. The FEIR may be prepared in conjunction with the COE Response to Comments and Record of Decision.

The Final EIR (FEIR) must address the issues discussed below and those identified in the enclosed comment letters.

The Sagamore Marsh is subject to flooding due to inland precipitation and coastal flooding events. The DEIR predicts the combined 100-year flood elevation as much lower than that shown by the FEMA evaluation. The FEIR must estimate site conditions at the time the FIRM maps were prepared, and present data and conclusions from the FIRM Study. Review of the current FIRM map indicates that much of the 100-year flood water enters the marsh by overtopping and/or breaching of the barrier beach system along Phillips Road. The predicted 100-year flood elevation for the Sagamore Marsh is the static flood level of Cape Cod Bay in the project area. If the current FIRM map and report will not accurately describe the area under proposed conditions, new equivalent information must be provided for review in the FEIR. If the FEIR information is found acceptable by the Towns, FEMA and MEMA, it should be used by the Town for decision-making purposes from the date of project implementation to the effective date of updated FEMA maps.

The preliminary information presented on the state-listed Species of Concern in the DEIR needs to be substantiated in the FEIR to ensure that the project does not impact its habitat. It is necessary to present the elevation of the habitat in the FEIR to ensure that the habitat will not be altered by the project.

The proponent should consider the use of two 6-foot stop logs, rather than a single 12-foot stop log, to control flow at the Canal Service Road culvert, if later mitigation following monitoring could involve the placement of some stop logs to restrict tidal flow. Control by stop logs may be more reliable than by partial closure of electric sluice gates.

The DEIR proposes construction of a temporary replacement Scusset Beach Access Road across the man-made channel and associated wetlands during construction of the new box culvert. The FEIR should consider segmenting construction of the box culvert to allow public passage over portions of the culvert site as construction proceeds. This should be possible since the proposed culvert is approximately 100 feet long. Elimination of the temporary crossing would further minimize project impacts to Wetland Resources. In addition, the FEIR should review the need to bypass tidal waters during construction, as proposed in the DEIR. Loss of a few tidal flushing cycles may not significantly damage the marsh resources and the implementation of the suggested mitigation may cause a greater impact.

The FEIR must contain revised drafts of the proposed Operation and Maintenance Manual and Monitoring Plan so they can be reviewed by agencies and the public.

The FEIR must contain a draft Section 61 Finding which identifies mitigation measures, parties responsible for their implementation, an implementation schedule, and the monitoring and management plan for the project. Copies of the FEIR must be circulated to those identified in the scope, those who commented on the DEIR, and FEMA.

May 31, 1996
DATE

Trudy Coxe
Trudy Coxe

Comments received : EOEA - 4/16/96
MCZM - 5/24/96
DEP/DWW - 1/4/95
DEP/SE - 12/12/95
NHP - 5/23 & 5/29/96
DEM/RC/MEMA - 5/24/96
Cape Cod Mosquito Control Project - 4/2/96
Sandwich Conservation Comm. - 5/24/96
Sandwich Board of Health - 5/23/96
Audubon - 5/24/96
G. Jacobsen - 5/8/96
Mrs. P. Jacobsen - 5/8/96

TC/DES/ds

To: Christy Foote-Smith@Policy@EOEA
Cc:
B--:
F m: Hanni Dinkeloo@DFW@FWE Westboro
Subject: re: Sagamore
Date: Wednesday, May 29, 1996 12:35:01 EDT
Attach:
Certify: N
Forwarded by: Christy Foote-Smith@Policy@EOEA

Forwarded to: Dave Shepardson@MEPA@EOEA
cc:
Forwarded date: Thursday, May 30, 1996 9:21:02 EDT
Comments by: Christy Foote-Smith@Policy@EOEA

------------------------- [Original Message] -------------------------

The Natural Heritage & Endangered Species Program has reviewed the Army Corps response to comments made by our program concerning the Sagamore Marsh Restoration Project.

The Army Corp has agreed that they will survey the elevation of the four-toed salamander population and has proposed to do this survey during the plans and specification phase. As modeled, the preferred alternative (6 x 12 culvert) water levels would normally be at or below the 4 foot elevation and higher water levels during storm events can be controlled through closure of the s ice gate. Therefore it appears that impacts to rare species habitat can be avoided once we know the actual elevation of this population under this alternative.

The Army Corp has also agreed to monitor the salamander population and its habitat prior to and following implementation of the project. This will allow us to safeguard the four-toed salamander population by monitoring the impacts to its habitat under the changed conditions.

It appears that that the Corps' proposed preferred alternative (6'H x 12'W culvert) and monitoring plan will provide the safeguards to assure that the four-toed salamander habitat is protected.

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
ONE WINTER STREET, BOSTON MA 02108 (617) 292-5500

WILLIAM F. WELD
Governor

ARGEO PAUL CELLUCCI
Lt. Governor

TRUDY COXE
Secretary

DAVID B. STRUHS
Commissioner

May 28, 1996

Joseph Ignazio, Director of Planning
Army Corps of Engineers, New England Division
424 Trapelo Road
Waltham, MA 02154-9149

Dear Mr. Ignazio:

I am in receipt of the Draft Environmental Assessment/Draft Environmental Impact Report for the Sagamore Marsh Restoration Project. Based on the information in this document, and pursuant to the submission of appropriate permit and license applications and review, the project appears to be permittable under the Massachusetts Wetland Protection Act (MGL c. 131, s. 40) and the Waterways Protection Act, MGL c. 91.

Under the Wetlands Protection Act, the project would be reviewed under the provisions of 310 CMR 10.53(4) and 310 CMR 10.32(5). In the case of freshwater wetlands, the wetland regulations give the issuing authority discretion to permit wetlands alterations which will improve the natural capacity of resource areas to protect the interests identified in the wetlands statute. Similarly, in coastal wetlands, wetland alterations may be allowed which will result in the restoration or rehabilitation of salt marsh. In either case however, the project will not be permitted without a variance of the wetland regulations if the project will have an adverse effect on rare species habitat. With respect to c. 91 waterways license review, the project will be reviewed and may be permitted as a minor project modification to a public service project.

I hope I have provided answers to you questions. Please feel free to contact me or Michael Stroman if you would like to discuss this further.

Sincerely yours,

Robert W. Golledge, Jr.
Acting Director
Division of Wetlands & Waterways

cc: Christy Foote-Smith

To: Dave Shepardson@MEPA@EOEA
Cc:
Bcc:
From: Christy Foote-Smith@Policy@EOEA
Subject: Comment on #10174
Date: Tuesday, May 28, 1996 14:36:54 EDT
Attach:
Certify: N
Forwarded by:

On Friday I received a voicemail message from Virginia Stack, a member of REPS (Responsible Environmental Protection for Sandwich), who wanted to be on record, on behalf of her organization, as being strongly in favor of the Sagamore Marsh Restoration Project. She can be reached at 508-888-6943 if you have any questions.

On the same day, I received voicemail from Dorothy Blickens, a prior commentator and resident who said she planned to fax comments. I have not received a fax at this time, however.

To: Christy Foote-Smith@Policy@EOEA
Cc: Richard Thibedeau
Bcc:
From: Richard Zingarelli@RC@DEM Boston -MEMA
Subject: Sagamore Marsh
Date: Friday, May 24, 1996 14:25:02 EDT
Attach:
Certify: N
Forwarded by: Christy Foote-Smith@Policy@EOEA

Forwarded to: Dave Shepardson@MEPA@EOEA
cc:
Forwarded date: Tuesday, May 28, 1996 8:51:27 EDT
Comments by: Christy Foote-Smith@Policy@EOEA

------------------------ [Original Message] ------------------------

I have reviewed the Corps response to the EOEA comments on the EA/Feasibility Study. Of the three comments submitted by DEM, they concurred with two (#2 and #3) and no further information is required with regard to those comments. Concerning the discrepancy in 100-year flood elevations between the Corps report and the FEMA Flood Insurance Study (FIS), they have correctly indicated that we do not know the reason for the discrepancy, and that DEM has requested backup documentation of the FIS from FEMA. The backup material should be reviewed by the Corps and the discrepancy resolved prior to construction of the project.

D.S

THE COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
OFFICE OF COASTAL ZONE MANAGEMENT
100 CAMBRIDGE STREET, BOSTON, MA 02202
(617) 727-9530 FAX (617) 727-2754

RECEIVED
MAY 2 199
MEPA

MEMORANDUM

To: Jan Reitsma, Director, MEPA Unit
From: Margaret Brady, Director, MCZM M. Brady
Date: May 24, 1996
Re: EOEA # 10174 Sagamore Marsh Restoration; Bourne, Sandwich

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The Massachusetts Coastal Zone Management (MCZM) Office has completed its review of the above-referenced Draft Environmental Impact Report (DEIR). MCZM has been an active participant throughout the development of this wetlands restoration project.

MCZM has already reviewed and commented on the bulk of information contained in the DEIR through the coordinated commenting process conducted by the Executive Office of Environmental Affairs' (EOEA) Wetlands Restoration and Banking Program (WRBP). In this coordinated EOEA comment process, MCZM raised several concerns regarding the culvert sizing alternatives, impact to existing properties, and the proposed monitoring program. Recently, an endangered species concern has also surfaced. MCZM believes that the DEIR and its inclusive documents do address the scope established in the Secretary's ENF Certificate and generally address MCZM's concerns. Where outstanding issues remain, MCZM feels that these issues can be satisfactorily addressed through the necessary permitting processes.

MCZM looks forward to continued coordination as this project moves into the implementation phase.

The proposed project may be subject to MCZM's federal consistency review. For further information on this process, please contact Jane W. Mead, MCZM Sr. Project Review Coordinator at 617-722-0798 x418.

MMB/BKC

cc:
Christy Foote-Smith, Wetlands Restoration and Banking Program
Truman Henson, Massachusetts Coastal Zone Management
Rebecca Haney, Massachusetts Coastal Zone Management

Massachusetts Audubon Society
Celebrating 100 Years of Conservation
1996

May 24, 1996

Trudy Coxe, Secretary
Executive Office of Environmental Affairs
100 Cambridge Street, 20th Floor
Boston, MA 02202

Attention: MEPA Unit

Re: EOEA # 10174; Sagamore Marsh Restoration Study, Bourne/Sandwich

Dear Secretary Coxe:

On behalf of the Massachusetts Audubon Society, I submit the following comments on the Draft Environmental Impact Report/Environmental Assessment (DEIR/EA) for the above-referenced project.

As you know, Massachusetts Audubon is a voluntary association of people, representing 55,000 member households, and dedicated to preserving the biological diversity and water resources of the commonwealth. The Society supports the efforts of the Massachusetts Wetlands Restoration and Banking Program (WRBP) to restore Sagamore Marsh and other degraded wetlands throughout the commonwealth. The Sagamore Marsh project was initiated with the goal of restoring salt marsh within this large wetland system, which presently is dominated by extensive stands of Phragmites australis. This site is one of many in Massachusetts and New England where reduction of tidal flow and/or placement of fill have converted salt marsh to a brackish or freshwater system. The result at Sagamore Marsh, as in some many other locations, has been a shift in the vegetative community, with loss of highly productive salt marsh in exchange for a relatively poorer and less diverse system dominated by Phragmites.

This project is one of many efforts underway throughout New England to restore salt marsh habitat. It is distinguished from other projects because of its relatively large scale: the entire marsh system encompasses about 188 acres of wetlands of various types. Of this total, approximately 50 acres are projected to be converted from Phragmites and forested/shrub swamp

208 South Great Road • Lincoln, Massachusetts 01773 • (617)259-9500

to salt marsh due modification of culverts and associated increases in tidal flushing. The large scale of the project provides an opportunity to accomplish wetlands restoration on an unprecedented scale for Massachusetts. At the same time, a project of this size involves somewhat higher levels of risk of unintended impacts, and requires more extensive planning and monitoring than a small project. The project is being managed through the Coastal America partnership effort, bringing together the resources of several federal, state, and nongovernmental agencies. Monitoring conducted for this project will not only have a bearing on future management decisions for Sagamore Marsh, but is also likely to contribute to scientific understanding of salt marsh restoration techniques for application at other sites. The Society supports this project and the efforts of Coastal America and the WRBP to restore and enhance wetland resources.

Alternatives Analysis

The DEIR/EA analyzes several alternatives for restoration of salt marsh at the site. Increased tidal flushing is proposed to be accomplished through installation of larger culverts and modification of the first part of the channel leading from Cape Cod Canal into the marsh. This restoration project is complicated by several factors, in addition to its size, including the effects of historic filling, the historic elimination of the mouth of the Scusett River, and development of areas surrounding the marsh. Because it would be infeasible to attempt to recreate the original conditions of the marsh prior to construction of the Cape Cod Canal and surrounding residential development, various alternatives were considered, each of which would restore some but not all of the historic salt marsh. The DEIR/EA analyzed the effects of each alternative upon surrounding resources and developments, as well as projected effects on the marsh itself. Factors considered included water supplies, groundwater, and septic systems. The preferred alternative is a responsible approach that can reasonably be expected to restore a significant amount of salt marsh, is feasible to accomplish, and has a low risk of negative effects on surrounding areas.

Monitoring

The DEIR/EA includes a description of monitoring of hydraulics, groundwater, and ecology, to be undertaken over a period of three to five years. The Society recommends that the WRBP and Army Corps of Engineers work with area educational institutions to explore the possibilities for establishing additional ecological monitoring programs for the marsh. The proposed measures are minimal considering the size and complexity of the marsh system. In addition to vegetative monitoring, monitoring of vertebrate and invertebrate species which may utilize different areas of the marsh as it changes following the proposed hydrological alterations would provide valuable data.

Long Term Planning

The preferred action is projected to result in the restoration of approximately 50 acres of salt marsh, within the overall 188 wetland system at the site. The hydrological alterations proposed in the preferred action should be considered as phase one of a longer term restoration, monitoring, and management program for Sagamore Marsh. After the marsh has adapted for several years to the altered tidal flushing regime, the WRBP and Army Corps of Engineers should evaluate whether additional actions would further enhance the wetland system. For example, application of Open Marsh Water Management techniques might be appropriate within the restored salt marsh area, both to reduce mosquito populations and to further enhance the salt marsh habitat. Future management decisions should be based upon the results of the ongoing monitoring program.

Thank you for the opportunity to comment.

Sincerely,

E. Heidi Roddis

E. Heidi Roddis
Environmental Policy Specialist

cc: Matthew Walsh, Army Corps of Engineers, New England Division
Christy Foote-Smith, WRBP
Robert Golledge, Mass. Department of Environmental Protection
Bourne Conservation Commission
Sandwich Conservation Commission
Armando J. Carbonell, Cape Cod Commission
Mass. Assoc. of Conservation Commissions

TOWN OF SANDWICH

THE OLDEST TOWN ON CAPE COD

SANDWICH CONSERVATION COMMISSION
16 JAN SEBASTIAN DR.
SANDWICH, MA 02563
888-4200

May 24, 1996

Army Corps of Engineers,
New England Division
Attn: Environmental
Resources Branch
424 Trapelo Road
Waltham, MA. 02154-9149

Dear Evaluation Division,

Acting in my capacity as the Sandwich Conservation Officer, I have completed a review of the Draft Environmental Impact Report for EOEA, EOEA File No. 10174 and the Draft Section 1135 Project Modification Report and Environmental Assessment, Volumes II & III for the Army Corps of Engineers New England Division, **Sagamore Marsh Restoration Study** in Bourne and Sandwich Massachusetts.

Following this review, I offer the following comments:

- The Corps study was obviously very intensive and appears to cover most issues raised by the public, local, state and federal agencies.

- I applaud the agencies' conservative approach to conversion of the habitat (limiting to 50 acres). However, it is imperative that lines of communication between the town(s) and the design and controlling agencies be established and remain open, post construction, to review reports of unexpected negative impacts (serious flooding or flooding of septic systems). An expansion of the proposed monitoring program should be part of a protocol if unanticipated impacts occur. Review of the results of the proposed monitoring program with designated town representatives at (at a minimum) bi-annual meetings may facilitate the local, state, federal lines of communication. But, if few, if any negative results are documented, expansion of the project should be considered.

- A comment letter generated by responses to the EOEA ENF incorrectly stated that "...under the Massachusetts Wetlands Protection Act, all wetlands are protected equally..." Salt Marsh under the Act and its regulations 310 CMR 10.32 (3) provides that a proposed project "...shall not destroy any portion of the salt marsh...shall not have an adverse impact on the productivity of the salt marsh...". 10.32 (5) allows a project which will restore or rehabilitate a salt marsh. Conversely, 310 CMR 10.55 (4)(b) (Bordering Vegetated Wetlands(BVW)) allows for the loss of up to 5000 square feet of BVW provided the area is replicated according to specific conditions.

- Assuming the project will enter the next phase, design and permitting, the agencies should begin to document existing conditions (eg. present flooding) onsite and along adjacent private lands to dispel any future perceived impacts. Property line surveys should document actual not perceived land ownership.

- Wetland delineations (Fresh water) should be monitored along Phillips Road for documentation/research purposes. Presently all areas within the Town of Sandwich boundaries are considered resource areas, either coastal dune or Coastal Dune/Barrier Beaches under the Wetlands Protection Act and Town of Sandwich Wetlands Bylaw.

- I request the agencies coordinate with the towns and the Massachusetts Division of Marine Fisheries (Anadromous Fish Project) during the design phase, to determine if appropriate conditions could or will exist, post construction, to establish an anadromous/catadromous fish run within the estuary.

- An effective redundant system to the proposed electric sluice gates must be designed and implemented to ensure controls remain available during catastrophic weather events.

- Protocol regarding control of the electric sluice gate must allow for input from an affected town. For example. In the case of an environmental disaster (eg.oil spill), the appropriate town agency may require the electric sluice gate to be secured to prevent contaminants from entering the estuary. The protocol must be established and agreed to by the town(s) representative and controlling agency prior to project implementation.

- An access road should be constructed along the easterly portion of the new canal to facilitate observations and maintenance.

- Upon completion of the project, the temporary access road and staging area(s) should be removed and replanted with grasses and maintained as a grassy corridor to create edge habitat.

May 24, 1996, Comments regarding Section 1135 Draft Modification Report and Environmental Assessment, Page 3.

The present dense *Phragmities* stands presently inhabiting the greatest portion of the Sagamore Marsh are of little value to the majority of the species utilizing this habitat. In addition, it has been demonstrated that the present condition presents a danger (fire danger and higher incidence of mosquito breeding) to the neighboring areas. With proper controls in place, the conversion of this brackish wetland to a salt marsh will greatly improve the productivity of this environment, creating a more diverse habitat and benefit a greater number of species overall, including humans.

If you have any questions, please contact me.

Sincerely,

Mark S. Galkowski

Mark S. Galkowski
Conservation Officer

xc: Board of Selectmen
Town Administrator
Conservation Commission
Board of Health
Director of Planning
Engineering
Bourne Conservation Commission
Bourne Natural Resources Dept.

DS

TOWN OF SANDWICH

THE OLDEST TOWN ON CAPE COD

(508) 888-4200

BOARD OF HEALTH

~~270 QUAKER MEETINGHOUSE ROAD~~
~~EAST SANDWICH, MASSACHUSETTS 02537~~
16 Jan Sebastian Drive, Box 8
Sandwich, Massachusetts 02563

May 23,1996

Army Corps of Engineers, New England Division
Attention: Environmental Resources Branch
424 Trapelo Road
Waltham, MA 02154-9149

Secretary Trudy Coxe
Executive Office of Environmental Affairs
100 Cambridge Street-20th Floor
Boston, MA 02202
Attention: MEPA Unit

RECEIVED
MAY 24 1996
MEPA

Re: Sagamore Marsh Restoration Project

Dear Executive Office of Environmental Affairs & Army Corps of Engineers,

This office has reviewed the draft report dated April 16, 1996 for the project referenced above.

Review of the report indicates a thorough investigation of the effects of such project on the concerns of this office.

Impacts on the existing septic systems servicing residential dwellings existing on Phillips Road on the basis of the report would be minimal if any. As the Marsh Restoration Study indicates fluctuation of ground water level is not expected to increase by more than 0.1 feet to 0.2 feet (1.2 to 2.4 inches). This minimal rise is confirmed by the Frimpter Method of Estimation of High Ground-Water Levels-Cape Cod Commission Technical Bulletin 92-001 which determines limited fluctuations of ground water levels within 300 feet of tidal bodies as determined by tidal observation as has been confirmed by the Marsh Restoration Study. This office agrees that ground water impacts on septic systems designed and installed per the 1978 and 1995 Title 5 Code would not be affected since such designs were and are required to take into consideration the ground water levels.

The few remaining undeveloped lots are not considered a concern with regards to septic system construction. Due to the delineation of the area as a barrier beach/dune resource area the Sandwich Board of Health regulation: Coastal: Beaches, Dunes, Banks and Barrier Beach Regulation adopted on March 24,1986 does not allow the construction of new septic systems on those lots.

Potential flooding of existing septic systems would be controlled by the use of electric sluice gates as outlined in the report and this office recommends same with strict guidelines for monitoring levels.

This office requests that a monitoring program be implemented by the Corps of Engineers which involves the Sandwich Board of Health. Use of such monitoring data and involvement by this office would be beneficial for the future design of repair septic systems and reviewing any unknown impacts.

Please contact this office with any questions.

Sincerely,

David B. Mason,RS,CHO
Health Agent

CC;file

NORTH SAGAMORE WATER DISTRICT
P.O. Box 133, 14 Squanto Road, Sagamore Beach, MA 02562
Tel: 508-888-1085 Fax: 508-888-1085*51

May 17, 1996

Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02154-9149

ATTN: Environmental Resources Branch

Dear Sir/Madame:

At our meeting on May 15, 1996, we, the Commissioners of the North Sagamore Water District, voted to express our concerns in letter form in regards to the salt marsh restoration project.

We have read the draft report of the environmental assessment and the safeguards that will be put into place in the event of any impact to our well.

However, there is nothing in this report to indicate whose responsibility it will be to correct any problems if any should arise.

We feel that a bond should be in place to ensure the safety of our well, as would be a normal procedure if this project was being done by a private contractor.

Although we are sure the project has merit, our responsibilities lie with the people whom we serve and, as you are aware, there are enough threats to water supplies now, without adding another "unknown".

For the Board

NORTH SAGAMORE WATER DISTRICT

Virginia Anderson

Virginia Anderson
Chairperson

VA/vrs

cc: Secretary Trudy Coxe

May 16, 1996

Planning Directorate
Formulation Division

Ms. Christy Foote-Smith, Director
Wetlands Restoration and Banking Program
Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, 20th Floor
Boston, Massachusetts 02202

Dear Ms. Foote-Smith:

Thank-you for your comments on the draft Project Modification Report/Environmental Assessment (DPMR/EA) for saltmarsh restoration at Sagamore Marsh. Your comments were contained in your letter dated April 16, 1996. The purpose of this letter is to provide you with our response to your comments. Our response follows the format of your letter.

MAJOR COMMENTS

Alternatives

1. We agree with you that additional restoration is possible through management of the restoration project, and this is supported by results of the hydraulic modeling. Early hydraulic modeling efforts for this study modeled the channel system with creekbank levees only in the immediate vicinity of Transect 4, as were shown by Transect 4. Our ecologist, Mr. Larry Oliver, subsequently indicated that, based on the review of aerial photography, creekbank levees were more extensive than had been modeled. The hydraulic model was therefore modified to include creekbank levees in the locations indicated by Mr. Oliver, and the estimated acres of restoration shown in the DPMR were determined.

Although it was expected that the addition of creekbank levees to the hydraulic model would increase water levels, water levels did not change significantly. Therefore, it appears that there will be sufficient water entering the marsh to allow for future additional restoration, up to the elevation allowed by the culvert opening, by managing the marsh to allow water to get in and out of low areas beyond creekbank levees. This could be accomplished by performing selective manipulation of the topography, by clearing existing overgrown side channels, or by letting tidal flushing eventually clear the side channels naturally. At least up to a point then, the factor limiting the amount of potential additional restoration appears to be the elevation of the marsh surface rather than the volume of water proposed to enter the marsh.

There would be a limit to the amount of additional restoration which could be achieved by these methods, as the volume of water would eventually become the constraining factor. However, for the changes which we made in the hydraulic model, it did not appear that the volume constraint was reached. In summary, we agree that there is potential for additional restoration through management of the marsh features. Unfortunately, there are not sufficient study resources remaining to quantify the additional potential acreage.

In addition, we believe that the best "model" for determining additional areas of the marsh which can be restored will be the marsh itself after tidal flushing is restored. Rather than expending funds to use the hydraulic model to quantify the additional potential restoration, we recommend active management of the project after construction to maximize restoration.

2. We agree that an additional 21 acres of restoration would be desirable. However, we continue to recommended the most cost effective alternative, the 6'H x 12'W culvert alternative. The reasons for selecting the recommended 6'H x 12'W alternative will be clarified in the "RECOMMENDATIONS" section of Appendix C - "Incremental Analysis" and in Section 8.2 of the DPMR - "Incremental Analysis".

The 6'H x 12'W alternative was identified in the incremental analysis as having the lowest marginal cost. Factors which we considered when deciding whether to move beyond the lowest marginal cost alternative include the need to maintain adequate drainage of the marsh peat, which may be important for plant growth and productivity; the need to avoid the potential for impact to four-toed salamanders; and the incremental cost. For the 10'H x 20'W alternative, the incremental cost of each additional output unit (acres) is $86,043, as shown in Table 7 of Appendix C - "Incremental Analysis", compared to $21,038 per acre for the first 50 acres restored by the recommended 6'H x 12'W alternative.

Both drainage and the potential for impact to four-toed salamanders would be worse with alternatives larger than the recommended 6'H x 12'W alternative. Enclosure 1 shows the approximated location of the salamanders, as reported to us by Mr. Brian Butler of Oxbow Wetlands Associates, the consultant who performed the rare species survey of the area. The figure shows that the four-toed salamanders are present between approximately elevation 4 feet NGVD and 6 feet NGVD at the south end of the marsh on the east side of the channel.

The location of the salamanders shown on Enclosure 1 should be considered approximate until a survey is performed. The reported accuracy of the 2-foot contour mapping shown on Enclosure 1 is +/- 1 foot, and the elevations shown along Transect 1 show that more information is needed to accurately determine the elevation of the salamander population.

Natural Heritage requested that we survey the location of the salamanders prior to construction to more accurately assess impacts, which we will do at the beginning of the plans and specifications phase. We anticipate that this requirement will increase the cost of plans and specifications by approximately $7,500. Natural Heritage also requested that we monitor the salamander habitat, which we will do prior to and following implementation. We anticipate that this requirement will increase the cost of plans and specifications and monitoring by approximately $2,500.

Enclosure 2 shows the high tide levels at Transect 1, which is north of the reported location of the salamanders, for existing conditions, the recommended 6'H x 12'W alternative, and for the 10'H x 20'W alternative. Enclosure 2 shows that the 1-year storm high tide level at Transect 1 under existing conditions is elevation 3.1 feet NGVD, and that it would increase to elevation 4.0 feet NGVD at this location with the recommended 6'H x 12'W alternative, and elevation 4.6 feet NGVD for the 10'H x 20'W alternative. (The sluice gates would be closed at the 1-year storm water level in the Canal to exclude the higher levels associated with more severe storms).

As stated, we intend to survey the flags marking the location of the salamanders, which were placed by Oxbow Wetlands Associates, at the beginning of the plans and specifications phase. Since a recommended alternative must be selected from this study at this time, we feel it is prudent to recommend the 6'H x 12'W alternative, for which we have reasonable evidence that the project can be implemented without impacting the salamanders.

Regarding the 10'H x 20'W alternative, it was designed with automatic tidegates because we determined that flow control gates would have to be closed an average of twice per month, rather than an average of once per year for the recommended 6'H x 12'W alternative. We felt that closing electric sluice gates that frequently would be an operational burden.

Enclosure 3 shows: a) the estimated water levels for the recommended 6'H x 12'W alternative with sluice gates being closed at the 1-year storm water level in the Canal, b) the estimated water levels for the 10'H x 20'W alternative with automatic gates closing at the twice per month (2x/month) tide level in the Canal, and c) the estimated water levels for the 10'H x 20'W alternative with sluice gates being closed at the 1-year storm water level in the Canal. These water levels are at Transect 2 and are representative of the water levels in the vicinity of homes adjacent to the marsh.

Under existing conditions, the water level resulting from the 1-year storm/1-year rainfall event is elevation 3.2 feet NGVD, and the water level resulting from the 100-year storm/100-year rainfall event is elevation 4.2 feet NGVD. Under existing conditions, one yard may be partially flooded by the 1-year event, and two yards may be partially flooded by the 100-year event, although this will be investigated further during the development of plans and specifications. There may be a need to acquire flowage easements over portions of properties which are affected by this project, which would add to the cost of the project.

As shown on Enclosure 3 (a), for the recommended 6'H x 12'W alternative with sluice gates being closed at the 1-year storm water level in the Canal, the water level resulting from the 1-year storm/1-year rainfall event would be elevation 3.7 feet NGVD, and the water level resulting from the 100-year storm/100-year rainfall event would be elevation 4.3 feet NGVD. Under those conditions, one yard may be partially flooded by the 1-year event, and four yards may be partially flooded by the 100-year event, although this will be investigated further during the development of plans and specifications.

As shown on Enclosure 3 (b), for the 10'H x 20'W alternative with automatic gates closing at the 2x/month tide level in the Canal, the water level resulting from the 1-year storm/1-year rainfall event would be elevation 3.9 feet NGVD, and the water level resulting from the 100-year storm/100-year rainfall event would be elevation 4.5 feet NGVD. Under those conditions, two yards may be partially flooded by the 1-year event, and five yards may be partially flooded by the 100-year event.

As shown on Enclosure 3 (c), for the 10'H x 20'W alternative with sluice gates being closed at the 1-year storm water level in the Canal, the water level resulting from the 1-year storm/1-year rainfall event would be elevation 4.2 feet NGVD, and the water level resulting from the 100-year storm/100-year rainfall event would be elevation 4.8 feet NGVD. Under those conditions, two yards may be partially flooded by the 1-year event, and fourteen yards may be partially flooded by the 100-year event.

Based on the above results, we determined that the control gates would have to be closed at the 2x/month tide level. We felt that closing electric sluice gates that frequently would be an operational burden. Therefore, we designed the 10'H x 20'W alternative with automatic tide gates.

As requested by you in your comments and for information only, we developed a cursory cost estimate which shows that the investment cost of the 10'H x 20'W alternative without automatic tide gates would be approximately $1,879,000. The incremental cost of the additional 21 acres of restoration would be $39,386 per acre, compared to $21,038 per acre for the first 50 acres restored by the recommended 6'H x 12'W alternative. If the sluice gates were closed at the 2x/month tide level, the flooding impacts would be those shown on Enclosure 3 (c). (Provided the control gates are closed at the same tide level, the water levels in the marsh would be the same whether flow is controlled by tidegates or sluice gates).

Applying the incremental analysis criteria to the 10'H x 20'W culvert without automatic tidegates, the factors to consider when deciding whether to move beyond the lowest marginal cost alternative, the recommended 6'H x 12'W alternative, include the need to maintain adequate drainage of the marsh peat; the need to avoid the potential for impact to four-toed salamanders; and the incremental cost. The potential for poor drainage and the potential for impacts to salamanders would be greater with the 10'H x 20'W alternative. In addition, there may be a need to acquire flowage easements over portions of properties affected by this project, which would add to the cost, and could affect public acceptance of the project.

For the reasons described above, we recommend the 6'H x 12'W alternative.

Regarding the use of stop logs or sluice gates to reduce the flood risk until more of the marsh is flooded, as described above, our hydraulic modeling did not show a significant decrease in flood levels when comparing the marsh system with creekbank levees to the marsh system without the levees. Therefore, our hydraulic modeling does not show that flood risk would be reduced as the area of marsh restoration was increased through management of the restoration.

For the recommended 6'H x 12'W alternative, the design calls for two 6'H x 6'W sluice gates and one 6'H x 12'W stop log frame, as shown in Appendix G - "MCACES Cost Estimate". The 10'H x 20'W alternative called for four 10'H x 5'W automatic tide gates and two 10'H x 10'W sluice gates.

3. There are no flow control structures proposed to be installed on the Scusset Beach Road culvert. Please refer to Section 9.1 of the DPMR, which states that "The recommended alternative has the following features: ... Install electric sluice gates on the marsh-side of the Canal Service Road culvert for primary flow control, and stop logs on the Canal side of the Canal Service Road culvert for backup closure ..." Please also refer to Sheet 1 - "Site Plan and Sections". If there is something in the report which indicates otherwise, please bring it to our attention so that we may clarify it.

4. The hydraulic model was used to optimize the channel width for all culvert alternatives including the 10'H x 20'W culvert. The analysis was run with a 20, 30, 40, and 50 foot channel and a tide range occurring two times per month. Increasing the channel width from 20 to 30 feet allows an additional 0.1 foot in water surface elevation, which was warranted based on the resulting additional restoration.

5. Geotechnical investigations performed for this study found that the channel banks are composed primarily of loose sands, which are not stable at a slope of 1 vertical to 2 horizontal unless supported by riprap. For that reason, it was determined that riprap is required on the channel side slopes up to elevation 5.0 NGVD for slope stability. Vegetation will be planted above that elevation to control erosion from rainfall and runoff. Based on the flow velocities determined by the hydraulic model, it was determined that riprap is required on the channel bottom for scour protection.

Project Design

1. The temporary road crossing was included because it was not safe to have camper trailers re-routed to the Canal Service Road, primarily because of the steep canal bank, frequent high winds, and pedestrian traffic. In addition, the environmental impact of installing and removing the crossing is expected to be minimal, since the channel is to be widened and deepened in that location anyway. However, the possibility of modifying or eliminating the crossing will be evaluated during the development of plans and specifications.

2. While the fine material removed from the bottom of the riprap channel could be replaced, the value of such an operation would probably be minimal. The existing sediments over the riprap bottom support typical estuarine benthic fauna. The exposed riprap supports at least low densities of oysters. The diversity provided by riprap appears to add to the overall value of the habitat.

Impact to Septic Systems

We intend to monitor groundwater levels, as described in Appendix F - "Monitoring Plan". We will add a statement to Section 7.3.3 of the DPMR stating that if the increase in groundwater levels is significantly greater than predicted, then the sluice gates would be closed as required to reduce the magnitude of groundwater rise.

The projected increase in groundwater levels in the vicinity of back yards along Phillips Road is less than one inch, as shown in Tables 3a and 3b of the DPMR. We will rely on the Bourne and Sandwich Boards of Health, who have the most knowledge of local conditions, to assess whether or not this small projected increase is acceptable.

We researched the town of Sandwich files to locate plans for septic systems along Phillips Road. The information we found in that effort was minimal, and no such effort was made for Bourne. We summarized the information and provided it to the Sandwich Board of Health with their copies of the DPMR. We will rely on the Bourne and Sandwich Boards of Health for their assessment of the potential for impacts to local septic systems.

We cannot attempt to identify the current adequacy of existing septic systems. The cost of inspecting all septic systems around Sagamore Marsh would be prohibitive. In addition, it is our understanding that under Title 5, the owner of a septic system which fails a Title 5 inspection is responsible for having the system repaired. If we were to inspect systems and identify those systems which currently fail under Title 5, the owners of the systems would be required under Title 5 to repair the system. We believe that owners would generally decline inspections for that reason.

To reiterate, our analysis shows that restoration will increase groundwater levels in the vicinity of back yards along Phillips Road less than one inch. We feel that this increase represents a negligible impact to septic systems. We will rely on the Bourne and Sandwich Boards of Health to assess whether or not this small projected increase is acceptable.

Flood Analysis

1. Existing Flood Levels. It appears from FEMA Flood Insurance Rate Maps that FEMA attributed the 100 year flooding inside the marsh to both overtopping of the beach and tidal flow passing through the culvert from the canal. Two-foot contour mapping used for the study shows an elevation 18 feet NGVD contour running along the entire

length of the beach dune with elevations as high as 22 feet NGVD in spots. With an elevation this high, overtopping should not increase the interior water level to 10 feet NGVD from a 100-year event. Analysis of flood waters entering through the proposed culvert from the canal indicate that the tide level inside the marsh would only reach 4.3 feet NGVD (excluding rainfall/runoff) with the gates fully opened.

It also appears that FEMA used a ground elevation of approximately 9 feet NGVD in the marsh, while the 2-foot contour mapping and surveyed transects show the marsh elevation to be on the order of 3 to 4 feet NGVD. This could account for the base flood elevation of 10 feet NGVD shown on the FEMA Flood Insurance Rate Maps.

It is our understanding that the Department of Environmental Management (DEM) has requested backup documentation of the Flood Insurance Study. We will review the information and coordinate with DEM and FEMA to attempt to clarify any discrepancies.

2. <u>Modified Flood Levels</u>. We concur. Comment noted.

3. <u>Impact on existing properties</u>. We concur. Our concern for impact on existing properties is one of the factors we considered in recommending the 6'H x 12'W alternative and recommending against larger culvert alternatives.

<u>Rare Species</u>

We will conduct an elevation survey at the start of the plans and specifications phase to develop sufficient information to ensure that the project will not have detrimental impacts on four-toed salamanders. We feel that there is sufficient information to select the recommended 6'H x 12'W alternative at this time. If the elevation survey reveals that there is a potential for detrimental impacts to the salamanders, then the project would be modified at that time to eliminate the potential for any detrimental impacts. Although we agree to the need for a monitoring program for this species, we intend to generate sufficient information before the project is implemented to have a strong assurance that the salamanders will not be impacted. The parameters which you suggested appear to be reasonable as the basis for monitoring.

Real Estate Requirements/Temporary Easements

The DPMR will be modified as requested.

Monitoring

Groundwater Monitoring

1. This comment has been forwarded to the USGS for consideration. We will seek their advice on whether sampling for chloride is warranted.

2. This comment has been forwarded to the USGS for consideration. We will seek their advice on whether the cost of installing another well is justified or whether an existing well can be used.

3. This comment has been forwarded to the USGS for consideration. We will seek their advice on the feasibility of the proposed sampling.

4. This comment has been forwarded to the USGS for consideration. We will seek their advice on whether the proposed level of 125 mg/l is appropriate. The only contingency plan available is to reduce the amount of water entering the marsh by closing the sluice gates as needed. A statement to this effect will be added to Section 7.3.4 of the DPMR.

Ecologic Monitoring

The monitoring section (Appendix F) is separated into tasks to be performed during the plans and specifications phase (Section 1.0) and tasks to be performed after construction (Section 2.0). The information collected during the Plans and Specifications phase is baseline data. We will make this clearer in the final report.

We intend to measure percent cover for all species in each plot. We will clarify this in the final report. We will record height of Spartina alterniflora at sample stations, but we expect its height will vary based on the degree of flushing and proximity to creeks. It is likely that variations in height form will be obvious. High representation of the short form of this species in the marsh may indicate restricted flushing. A high representation of the tall form of _Spartina alterniflora_ in the interior of the marsh will suggest a higher level of tidal exchange than predicted. We feel that percent cover alone will be sufficient to monitor the success of the project in terms of other marsh species.

The marsh stations will be sampled each year for five years following project implementation as indicated in Appendix F, Section 2.1.2. The monitoring plan suggests terminating sampling only for eelgrass if the results indicate that adverse changes are not occurring. We anticipate that any effects on eelgrass would occur relatively rapidly because of the small but rapid change in channel habitats with the project.

Our primary purpose for monitoring is to generate information to assess whether salt marsh is being restored or whether any adjustments are needed to achieve success. We feel that the depth of soil water will provide more useful information for identifying potential problems than soil water salinity. However, soil water salinity can most likely be added to the program with little increase in effort. We can discuss appropriate methods when the sampling plan is developed further during the plans and specifications phase.

We will make a determination on how tide height information will be collected (e.g., direct measurement or markers) during the development of plans and specifications. In general terms, it will be based on measurements of the level of flooding relative to a measured surface elevation.

Sample size will be determined during the plans and specifications phase. We normally prefer to use rectangular shaped plots. We can discuss the appropriate plot size as well as numbers and locations of plots and transects when the final sampling program is developed during the plans and specifications phase. Sample plot size will be adjusted if stations are located in the shrub/forested swamp.

We feel that the existing photography is adequate to represent the vegetation conditions on the marsh prior to construction.

The eelgrass sampling is being conducted to monitor the condition of eelgrass in the channel upstream of the existing riprap portion. There is very little eelgrass (a few culms) in the portion of the channel that presently contains riprap. Recolonization of the reconstructed channel by eelgrass would be dependent on the return of sediments to the channel bottom which will take a relatively long time. Presently, the highest value inhabitants of the riprap channel are the oysters (also present at very low density) which are associated with the hard substrate. The nature of the change (depth and possibly clarity) in the habitat in the upstream portion of the channel where dense eelgrass exists suggest that little change to the benthic community will occur.

We will attempt to provide the monitoring results in a format that fits your data base.

Mosquito Control Monitoring

Comment noted.

Rare Species Monitoring

Please refer to our response under "Rare Species" above.

Operation and Maintenance

Consistent with all other Corps of Engineers projects which are turned over to the non-Federal sponsor for operation and maintenance, we will provide the non-Federal sponsor with an "Operation and Maintenance Manual" outlining specific tasks to be performed. These tasks are expected to be consistent with those outlined in Section 9.3 of the DPMR.

You are correct in your understanding that the Corps Cape Cod Canal field office could operate the sluice gates under a Memorandum of Understanding to be executed at a later date. The gates would be operated as specified by the "Operation and Maintenance Manual" which is expected to be consistent with Section 9.3.1 of the DPMR.

Our regulations require that the non-Federal sponsor assume all costs for repair, replacement, and rehabilitation. Therefore, we cannot accept a limit to the Commonwealth's financial obligation for repair, replacement, and rehabilitation.

Remediation

Performance criteria will be established during the plans and specifications phase. The performance criteria will support the objectives listed on Pages 2 and 3 of Appendix C. Given that this is a proactive restoration project, we do not anticipate applying stringent performance criteria.

The primary remedial measures would be modifications to tidal flow by restricting flow through the culverts. Other remedial measures could be developed based on the information generated through monitoring.

OTHER COMMENTS

Feasibility Study

2.1 Coastal America. Section 2.1 of the DPMR will be modified as requested.

2.3 Agency. Section 2.3 of the DPMR will be modified as requested.

Figure 2 (EA). During the time that construction will be performed at the Canal Service Road culvert, users of the Canal Service Road are expected to consist primarily of pedestrians, bikers, rollerbladers, and occasional Corps work trucks. If these users are traveling from west to east, for example, they will travel from the Canal Service Road, over the temporary access road, down Scusset Beach Road, and back onto the Canal Service Road in the vicinity of the fishing pier. No construction will be necessary in the vicinity of the fishing pier to accommodate the users.

3.1 Existing Conditions. Section 3.1 of the DPMR will be modified as requested.

Environmental Assessment

Figure 5. We decided to focus the benthic core sampling in the portion of the channel directly impacted by construction. Salinity levels in the channel are apparently quite high under existing conditions; therefore, the benthic community in upstream portions of the channel is expected to experience minor changes.

Fish and Wildlife Evaluation. We normally use existing information as the primary source for predicting project effects on fish and wildlife. It would be extremely time consuming and prohibitively expensive to conduct comprehensive fish and wildlife studies for every EA. The information in the EA describes the species typical of the existing and predicted habitats of the study area. Fish and wildlife sampling would add little to the analysis in terms of predicting effects of the project.

EA-15. We will modify the EA appropriately.

EA-17. We did not monitor salinity levels in the tidal creek at different locations or seasonally. Limited samples indicate that the salinity varies sharply near the inlet with sea water salinity levels during an incoming tide and lower salinity during an outgoing tide as is typical of an estuarine setting close to a source of undiluted sea water. The very high salinity (28 ppt) measured at the main channel confluence shown in Figure 5 of the EA indicates that salinity attains a level sufficient to maintain estuarine conditions throughout the majority of the channel. This sample reflects growing season salinity during a high spring tide. Organisms inhabiting the channel must be adapted to the growing season extremes that this sample reflects.

EA-17 Change in Wetland Area. These sections will be clarified in the final report. The shape and tidal dynamics of the site cause the largest changes in tidal range to occur nearest the inlet. In this area a small increase in wetland area may occur. Where the width of the marsh expands, the tide levels increase very little, and the area of wetland is not expected to increase. Detailed mapping of the wetland edge during the plans and specifications phase will confirm this prediction.

Table 8 (After EA-20).
1. Chimney swifts will be revised to N for feeding, resting, and overall. Swallows feed over common reed marshes and sometimes roost in large numbers at certain times of the year. Common reed marshes supply large numbers of insects which swallows eat. Therefore we expect an overall decrease in the value of the habitat for swallows.

2. Kingfishers were listed as + for feeding and overall because of the anticipated increase in the value of the marsh for fish. The + for resting will be revised to N. Kingfishers were observed using the salt marsh portion of the existing marsh.

3. Given that common reed marsh is generally regarded as low value habitat, the expected increase in the food component that will occur with the project is expected to benefit skunks and other animals that may feed on the marsh. Deer use is not expected to drop since the quality of the food component of the habitat is expected to increase, while sufficient cover is maintained. The Division of Fisheries and Wildlife concurred with this prediction. The white-footed mouse will be added to the list.

4. This Table has been reviewed by the Massachusetts Division of Fisheries and Wildlife and the Natural Heritage Program. We followed their recommendations regarding reptiles and amphibians. The table contains a comprehensive list of species likely to be present at the habitats present at the Sagamore Marsh. We felt it would be better to list species that could be present but may not be present rather than to exclude species.

EA-22. We will revise the final report to indicate that open water marsh water management or other mosquito control measures will be implemented as needed.

EA-23. We feel that the riprap will provide equivalent water quality protection to bioengineering as well as providing a hard substrate for oysters in addition to the engineering considerations.

This concludes our response to your comments contained in your letter dated April 10, 1996.

Regarding the Draft Project Cooperation Agreement (DPCA), our Acting Division Counsel has reviewed the changes requested by you and your counsel. Our Acting Division Counsel has prohibited us from allowing the phrase "... subject to the availability of funds ..." in relation to funds to be provided by the non-Federal Sponsor. This phrase was proposed by your counsel to be inserted in ARTICLE II, paragraph A and in ARTICLE VI, paragraphs C and D1. Please see the enclosed memo from our Acting Division Counsel.

We have enclosed a copy of the executed PCA for Provincetown Harbor, Massachusetts which may be of assistance in obtaining approval from your counsel regarding the required wording. ARTICLE VI of the executed PCA discusses payment by the Local Sponsor, and does not contain the phrase "... subject to availability of funds...". The Provincetown PCA was signed by the Commissioner of the Department of Environmental Management, the Attorney General, and the Governor.

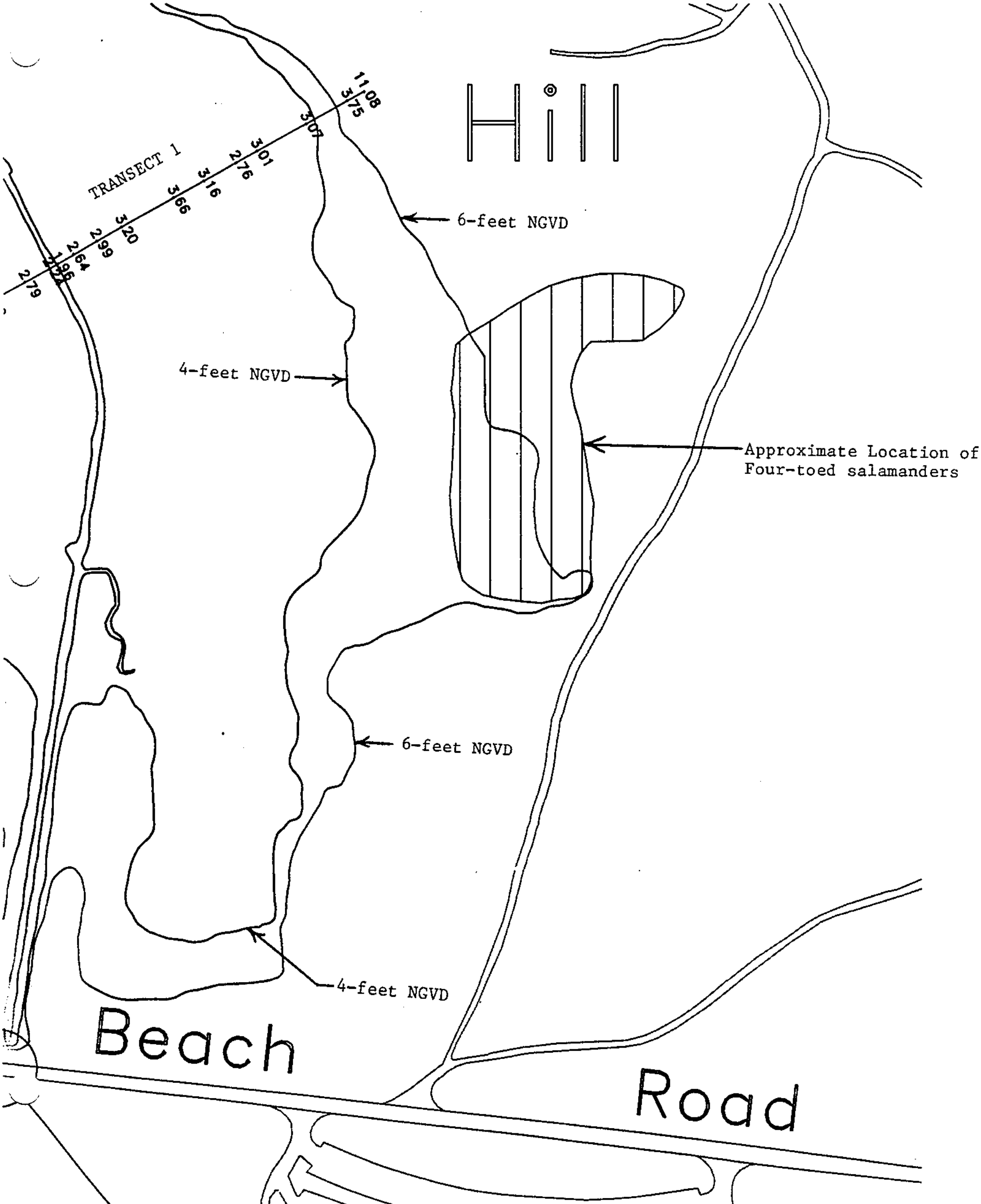
Our Acting Division Counsel has allowed us to change the wording in the "hold and save" clause contained in ARTICLE IX - "INDEMNIFICATION", as requested by your Counsel. Please see the enclosed DPCA which contains this revision.

If you have any questions or comments, please contact the Study Manager, Matthew Walsh, at (617) 647-8647, or the Section 1135 Program Manager, Mike Keegan, at (617) 647-8087.

Sincerely,

Joseph L. Ignazio
Director of Planning

Enclosures


Hill
TRANSECT 1
1108
375
307
301
276
316
366
320
299
264
196
279
6-feet NGVD
4-feet NGVD
Approximate Location of
Four-toed salamanders
6-feet NGVD
4-feet NGVD
Beach
Road

Enclosure 1

High Tide Levels* at Transect 1 - Gates Closed at 1-year Storm Level

Frequency of Tide Level in Canal	High Tide Level in Canal FT NGVD	High Tide Level at Transect 1		
		Existing culvert FT NGVD	6'Hx12'W culvert FT NGVD	10'Hx20'W culvert FT NGVD
8 x per month astronomic	5.0	3.0	3.6	4.0
2 x per month astronomic	5.6	3.0	3.7	4.2
Maximum astronomic	6.5	3.1	3.9	4.5
1-year storm	6.9	3.1	4.0	4.6
10-year storm	8.3	3.1	4.0	4.6
50-year storm	9.9	3.1	4.0	4.6
100-year storm	10.4	3.1	4.0	4.6

* Runoff is not included.

(a) Operating Plan: Electric sluicegates shut at one-year storm elevation of 6.9 feet NGVD in Canal.

Water Level at Transect 2
(assuming peak runoff is coincident with high tide)

Frequency of Tide Level in Canal	1-year runoff		10-year runoff		50-year runoff		100-year runoff	
	Existing culvert FT NGVD	6'Hx12'W culvert FT NGVD	Existing culvert FT NGVD	6'Hx12'W culvert FT NGVD	Existing culvert FT NGVD	6'Hx12'W culvert FT NGVD	Existing culvert FT NGVD	6'Hx12'W culvert FT NGVD
1-year storm	3.2	3.7	3.3	3.8	3.7	4.2	3.8	4.3
10-year storm	3.5	3.7	3.6	3.8	4.0	4.2	4.1	4.3
50-year storm	3.6	3.7	3.7	3.8	4.1	4.2	4.2	4.3
100-year storm	3.6	3.7	3.7	3.8	4.1	4.2	4.2	4.3

(b) Operating Plan: Automatic tidegates shut twice per month at elevation 5.6 feet NGVD in Canal.

Water Level at Transect 2
(assuming peak runoff is coincident with high tide)

Frequency of Tide Level in Canal	1-year runoff		10-year runoff		50-year runoff		100-year runoff	
	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD	Existing culvert FT NGVD	10'Hx20' culvert FT NGVD	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD
2 x per month	3.2	3.9	3.3	4.0	3.7	4.4	3.8	4.5
1-year storm	3.2	3.9	3.3	4.0	3.7	4.4	3.8	4.5
10-year storm	3.5	3.9	3.6	4.0	4.0	4.4	4.1	4.5
50-year storm	3.6	3.9	3.7	4.0	4.1	4.4	4.2	4.5
100-year storm	3.6	3.9	3.7	4.0	4.1	4.4	4.2	4.5

(c) Operating Plan: Electric sluicegates shut at one-year storm elevation of 6.9 feet NGVD in Canal.

Water Level at Transect 2
(assuming peak runoff is coincident with high tide)

Frequency of Tide Level in Canal	1-year runoff		10-year runoff		50-year runoff		100-year runoff	
	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD	Existing culvert FT NGVD	10'Hx20' culvert FT NGVD	Existing culvert FT NGVD	10'Hx20'W culvert FT NGVD
1-year storm	3.2	4.2	3.3	4.3	3.7	4.7	3.8	4.8
10-year storm	3.5	4.2	3.6	4.3	4.0	4.7	4.1	4.8
50-year storm	3.6	4.2	3.7	4.3	4.1	4.7	4.2	4.8
100-year storm	3.6	4.2	3.7	4.3	4.1	4.7	4.2	4.8

CAPE COD COMMISSION

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May 15, 1996

Earl C. Richardson
Colonel, Corps of Engineers
Division Engineer
424 Trapelo Road
Waltham, MA 02254-9149
Attn: Environmental Resources Branch

Secretary Trudy Coxe
Executive Office of Environmental Affairs
100 Cambridge Street - 20th Floor
Boston, MA 02202
Attn: MEPA Unit

Dear Colonel Richardson and Secretary Coxe:

I am pleased to submit comments on behalf of the Cape Cod Commission staff on the Army Corps of Engineers Sagamore Marsh Restoration Study for Bourne and Sandwich.

The Cape Cod Commission is supportive of wetland restoration initiatives. The Barnstable County Regional Policy Plan, adopted in September 1991, contains a policy which states in part "measures to restore altered or degraded inland and coastal wetlands . . . should be encouraged." We are currently working with Cape Cod communities on several wetland restoration initiatives, of which the Sagamore Marsh project is the largest.

Under Sections 12(i) and 13(b) of the Cape Cod Commission Act, the Cape Cod Commission is responsible for the regulatory review of any development project in Barnstable County for which an Environmental Impact Report is required by the Executive Office of Environmental Affairs (EOEA). The Commission is required to hold a public hearing on the project within 45 days of the certification of the Final Environmental Impact Report by EOEA and would need to receive an application prior to the hearing.

At this time, we have the following comments on the Draft Project Modification Report /Environmental Assessment:

<u>Alternatives Analysis</u>

The Sagamore Marsh project is a significant wetland restoration effort which offers tremendous potential for increasing our understanding of salt marsh ecology and wetland restoration techniques. The Marsh has been degraded by both restricted flushing as well as direct filling. This area once contained more than 350 acres of salt marsh but now supports only 11.7 acres of salt marsh.

We have reviewed the various alternatives for culvert and channel sizing analyzed in the Study. While the proposed alternative (6' x 12' culvert in a 12' channel) appears to be the most cost effective alternative in the study, we would like to see further examination of larger culvert alternatives and/or selective removal of fill and creation of channels that would allow more than 50 acres of the Marsh to be restored. Given the findings of the study that the larger culverts would also not have an adverse impact with regard to the identified constraints (flooding, navigation, wells, septic systems) it seems appropriate to look at alternatives which would provide the maximum environmental benefit. We support the comments of the Executive Office of Environmental Affairs (dated April 16, 1996) with regard to this issue.

With regard to the cost estimates for the various alternatives, it is not clear in the study why a 30' channel would be needed in conjunction with a 10' x 20' culvert? The selection of appropriate flood control gates is also confusing. Why are automatic tide gates needed for the larger culvert sizes rather than electric sluice gates? How will the electric gates function in the event of a storm when power is lost? Are there other, most cost-effective flood control alternatives that can be used to reduce the cost of a larger culvert? It might be helpful to break down the cost of each alternative in a table in the final study (culvert cost, channelizing cost, cost of the gates, construction costs, etc.).

Water Resources

The Draft Project Modification Report/Environmental Assessment addressed the effect of increased tidal flow on groundwater conditions including septic systems and public water supply wells. The report indicated that tidal pulses in the marsh were readily attenuated in the surrounding groundwater due to the permeability of the aquifer. Field data indicated that tidal pulses are attenuated within 42 feet. Groundwater levels were not expected to increase more than 1.2 to 2.4 inches in the marsh channel and therefore would be would be significantly less away from the channel.

The groundwater study indicated that the public water supply well (Beach Well) derived its water from the upgradient area to the west and that there was little connection to the marsh. Groundwater flow from the marsh to the well was not induced by pumping in any of the USGS model simulations. The DEM community supply wells are screened in the lower confined aquifer.

Based on similar studies conducted by the Cape Cod Commission's Water Resources Office and a review of this study, we support the conclusion of this study that the proposed project can be accomplished without adverse impacts to public water supply wells or septic systems with adequate separation to groundwater.

Wetland & Wildlife Habitat Resources

The Study notes the presence of the four-toed salamander, a state species of concern on the site. We share the concerns of the Natural Heritage and Endangered Species program and would recommend that additional work be done to determine whether or not the habitat of this species will be altered by the proposed construction.

The proposed temporary access road will alter a small area of salt marsh. Are there alternatives available that could eliminate the need for this alteration? If not, is the footprint of the proposed temporary access also proposed for restoration at the completion of construction?

Finally, we are supportive of the comments made by the Wetlands Restoration and Banking Program and Coastal Zone Management with regard to the proposed ecological monitoring on the site. To the extent that these monitoring recommendations will increase the cost of the project, we believe that they will provide valuable information for future marsh restoration projects and increase understanding of salt marsh ecology and ecological succession. Much of this research may be able to be accomplished in conjunction with local research institutions and scientists.

We appreciate this opportunity to provide comments on this project and look forward to working with both the Army Corps of Engineers and the Executive Office of Environmental Affairs on this and other wetland restoration initiatives.

Sincerely,

A.J. Carbonell

Armando J. Carbonell
Executive Director

cc: Christy Foote-Smith, EOEA
Richard Prince, Bourne Representative, Cape Cod Commission
Lance Lambros, Sandwich Representative, Cape Cod Commission
Karen Sherman, Bourne Town Planner
Reena Shaw, Bourne Conservation Administrator
Marie Blaney, Sandwich Town Planner
Mark Galkowski, Sandwich Conservation Administrator

50 Ackley Cem. Rd.
Colchester, CT 06415
8 May 1996

Christy Foote-Smith
Executive Office of Environmental Affairs
100 Cambridge Street
Boston, Ma. 02202

Dear Ms. Foote-Smith

I am writing to comment on the presentation I heard on 7 May, 1996 regarding the proposed restoration of part of the Sagamore Marsh. I am directly interested by virtue of my family home, of many years, on Williston Road in Sagamore Beach.

As a professional geologist I was very impressed by the quality of hydrogeologic data and interpretation. To my mind the concerns of residents regarding septic systems and the water supply well should be fully put to rest. The obvious environmental improvements expected from this project will be an extremely valuable asset to this community and the region.

Sincerely,

Garry Jacobsen
Garry Jacobsen

cc: Earle C. Richardson

Box 357
Sagamore Beach
MA 02562

May 8, 1996

Dear Mr. Richardson,

I just want to say that I, for one, am very much in favor of reviving the Sagamore marsh into the salt water marsh it once was. I can see all the advantages in this project and I hope very much to see it come to pass.

With high hopes and best wishes,

Sincerely,

Mrs. Peter Jacobsen

Public Notice

US Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02254-9149

Date: April 19, 1996
Comment Period Closes: May 24, 1996
File No: NA
In Reply Refer To: Evaluation Division

RESTORATION OF THE SAGAMORE SALT MARSH
UNDER SECTION 1135 OF THE
WATER RESOURCE DEVELOPMENT ACT OF 1986
PROJECT MODIFICATIONS FOR THE IMPROVEMENT OF THE ENVIRONMENT

SAGAMORE MARSH, BOURNE AND SANDWICH, MASSACHUSETTS

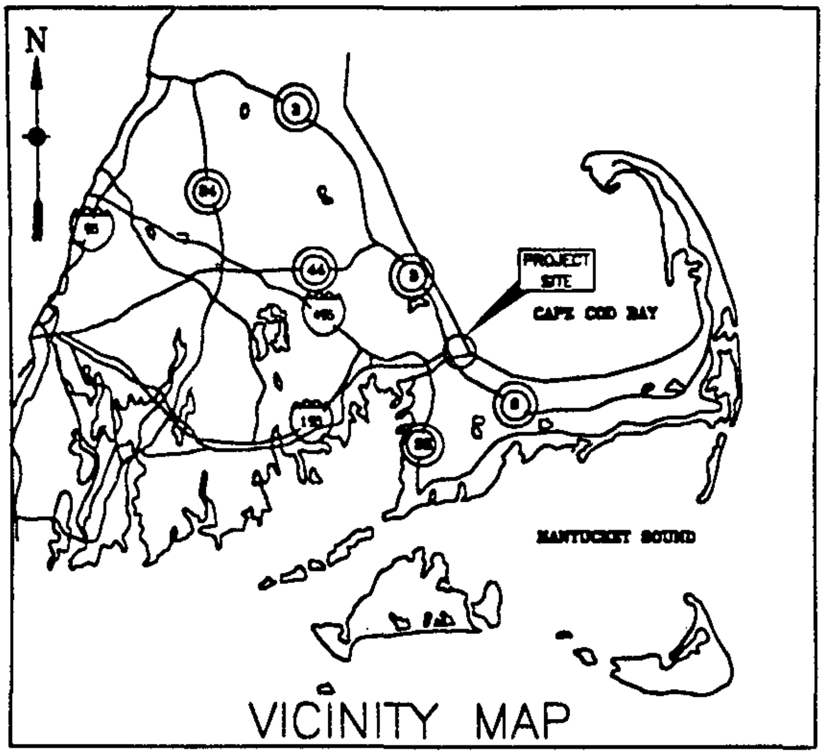
Interested parties are hereby notified that the Army Corps of Engineers, New England Division, has completed an investigation evaluating a project to restore salt marsh and estuarine habitat in a portion of the Sagamore Marsh in Bourne and Sandwich, Massachusetts. (See Figure 1.) This work is being conducted at the request of the Massachusetts Executive Office of Environmental Affairs. The work is authorized under Section 1135 of the Water Resources Development Act of 1986 (33 U.S.C. 2294 et seq.). Attachment No. 1 lists pertinent laws, regulations and directives.

Project Description

The recommended alternative for this project involves the installation of culverts through Scusset Beach Road and the Cape Cod Canal service road, or bike path, and increasing the size of the existing outlet channel (Figure 1).

The proposed culverts under each road crossing would be 6-feet high by 12-feet wide. The set of culverts beneath the bike path would be equipped with electric sluice gates and a backup flow control system to control the level of tidal water during coastal flooding events.

The existing 1,300 foot riprap channel would be deepened and widened to improve hydraulic conveyance capacity. The culverts beneath the Canal service road would be placed at the same elevation and slope as the existing culvert. Between the Canal service road and Scusset Beach Road, siltation will be removed to deepen the channel. On the marsh-side of the Scusset Beach Road culverts, the channel would slope upward to the upstream end of the riprap to meet the existing invert elevation. The bottom width would be increased from approximately 4 ft to 12 ft by excavating and moving the east bank of the channel 8 ft toward the east and replacing the 2:1 side slope. Stone protection would be replaced up to elevation 5 ft NGVD on the east bank. The remainder of this bank up to existing grade would be topsoiled and hydroseeded with an erosion control mixture.



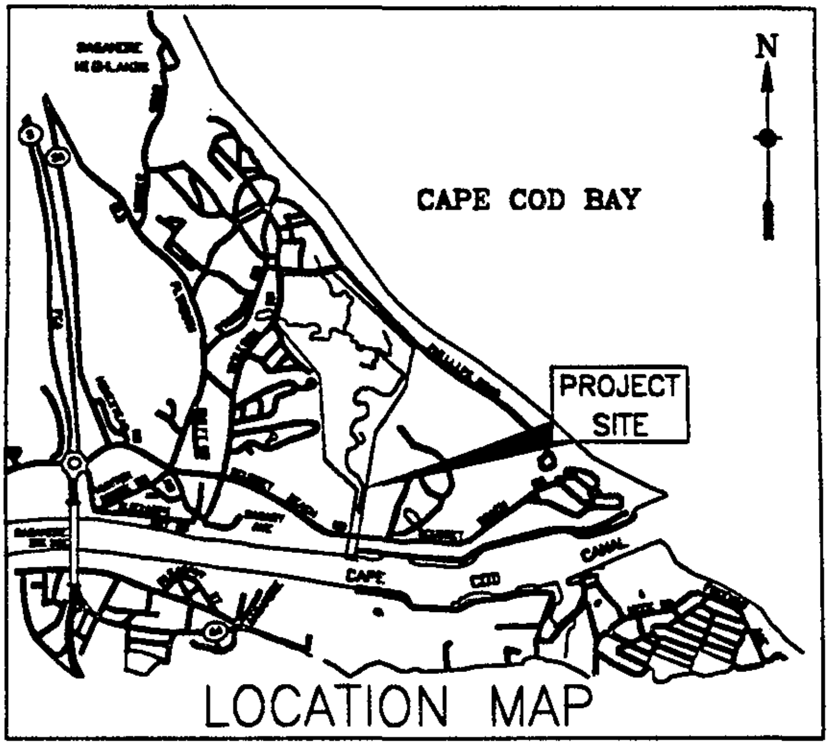


FIGURE 1

PROJECT LOCATION

SCALE: NOT TO SCALE

Two upland staging areas would be established. One would abut the east side of the downstream channel segment and the south side of Scusset Beach Road. The second would be located on the west side of the riprap channel above Scusset Beach Road. A work area will be cleared of vegetation along the west side of the riprap channel bank above Scusset Beach Road and along the east side of the channel between the bike path and Scusset Beach Road. Excavated material that can not be reused for construction will be disposed of at the town landfill or in a suitable offsite upland location.

Construction would take place during the 9-month period between August 1 and May 1 with the culvert and channel work occurring after October 1. The following general sequence is proposed: 1) Install erosion controls and clear staging areas; 2) construct upstream channel segment; 3) install bypass CMP and roadway; 4) install bike path culvert and gates; 5) install Scusset Beach Road culvert; 6) construct downstream channel segment.

Mosquito control will be implemented as needed by the local sponsor.

Purpose of Work: The purpose of this project is to modify the existing culvert and channel through the Cape Cod Canal to restore estuarine habitat, salt marsh and the associated values to fish and wildlife. The majority of the Sagamore Marsh contains degraded freshwater/brackish habitat dominated by common reed (*Phragmites australis*) and freshwater wetland vegetation due to restrictions in tidal flow and filling with dredged material. Common reed is a nuisance species with low value for fish and wildlife. Periodic tidal flushing of the marsh with salt water is necessary to restore valuable estuarine habitat.

Additional Information: Additional information may be obtained from Mr. Matthew Walsh, New England Division, U.S. Army Corps of Engineers, Formulation Division, 424 Trapelo Road, Waltham, Massachusetts 02254-9149, telephone number (617) 647-8647.

Coordination: The proposed work is being coordinated with the following Federal, State, and local agencies.

U.S. Environmental Protection Agency
National Marine Fisheries Service
U.S. Fish and Wildlife Service
U.S. Geological Survey
Massachusetts Wetlands Restoration and Banking Program
Massachusetts Office of Coastal Zone Management
Massachusetts Department of Environmental Management
Massachusetts Division of Marine Fisheries
Massachusetts Division of Fisheries and Wildlife
Massachusetts Natural Heritage Program
Massachusetts Division of Wetlands and Waterways
Massachusetts Historical Commission
Bourne Conservation Commission
Sandwich Conservation Commission

Environmental Impacts: An Environmental Assessment and Finding of No Significant Impact has been prepared and is available for public review upon request. A determination has been made that an Environmental Impact Statement for the proposed restoration project is not required under the provisions of the National Environmental Policy Act of 1969.

Clean Water Act: A preliminary Clean Water Act, Section 404(b)(1) evaluation has been completed for the project. State Water Quality Certification will be obtained prior to implementation.

Endangered Species: Coordination with the U.S. Fish and Wildlife Service and National Marine Fisheries Service has taken place and determined that there are no Federally listed endangered or threatened species in the proposed project area. Coordination with the Massachusetts Natural Heritage and Endangered Species Program indicated that four-toed salamanders, a State Species of Concern, are present at the site. The proposed project is not expected to impact four-toed salamanders; this will be verified during the development of plans and specifications.

Cultural Resources: The proposed work is being coordinated with the Massachusetts State Historic Preservation Officer in compliance with Section 106 of the National Historic Preservation Act of 1966, as amended.

Executive Order 11988 Floodplain Management: This project must be located in the floodplain to achieve the project purpose and will have no adverse impacts on floodplains.

Alternatives: Four alternatives to the proposed action, including the No Action Alternative, are being considered in the Corps Feasibility Study process. If no action is taken by any authority to restore the salt marsh, the marsh will continue to exist in its present degraded condition. The improvements in fish and wildlife resource value that would accrue with the project would not be achieved.

The second alternative consisted of various culvert size combinations equipped with automatic tide gates for primary flood control at the existing inlet.

The third alternative consisted of various culvert size combinations at the existing inlet equipped with electric sluice gates for primary flood control. The proposed plan was selected from among the culvert size combinations within this alternative.

The fourth alternative involved re-establishing the connection of the Sagamore Marsh to tidal flow at the historical connection through Scusset Beach near the existing entrance to the Canal. This alternative would involve reconstruction of a channel in the location of the historic channel through Scusset Beach. This alternative was beyond the scope of the existing study and was eliminated from detailed study.

Any person who has interest which may be affected by the proposed project may request a public hearing. The request must be submitted in writing to me within 30 days of the date of this notice and must clearly set forth the interest which may be affected and the manner in which the interest may be affected by the activity.

A public information meeting will be held on Tuesday evening, May 7 at 6:30 PM at the Hoxie School in Bourne, Massachusetts.

Please bring this notice to the attention of anyone you know to be interested in the project. Comments are invited from all interested parties and should be directed to me at 424 Trapelo Road, Waltham, MA 02254-9149, ATTN: Environmental Resources Branch within 30 days of this notice.

for [signature] LTC, DDE
Earle C. Richardson
Colonel, Corps of Engineers
Division Engineer

Attachment 1

PERTINENT LAWS, REGULATIONS AND DIRECTIVES

The proposed activity has been reviewed in accordance with the following laws and executive orders as applicable:

Federal Statutes

Preservation of Historic and Archaeological Data Act of 1974, as amended, 16 U.S.C. 469 et seq.

Clean Air Act, as amended, 42 U.S.C. 7401 et seq.

Clean Water Act of 1977 (Federal Water Pollution Control Act Amendments of 1972) 33 U.S.C. 1251 et seq.

Coastal Zone Management Act of 1972, as amended, 16 U.S.C. 1431 et seq.

Endangered Species Act of 1973, as amended, 16 U.S.C. 1531 et seq.

Estuarine Areas Act, 16 U.S.C. 1221 et seq.

Federal Water Project Recreation Act, as amended, 16 U.S.C. 4601-12 et seq.

Fish and Wildlife Coordination Act, as amended, 16 U.S.C. 661 et seq.

Land and Water Conservation Fund Act of 1965, as amended, 16 U.S.C. 4601-4 et seq.

Marine Protection, Research, and Sanctuaries Act of 1972, as amended, 33 U.S.C. 1401 et seq.

National Historic Preservation Act of 1966, as amended, 16 U.S.C. 470 et seq.

National Environmental Policy Act of 1969, as amended, 42 U.S.C. 4321 et seq.

Rivers and Harbors Act of 1899, as amended, 33 U.S.C. 401 et seq.

Watershed Protection and Flood Prevention Act, as amended, 16 U.S.C. 1001 et seq.

Wild and Scenic Rivers Act, as amended, 16 U.S.C. 1271 et seq.

Executive Orders

Executive Order 11988, Floodplain Management, 24 May 1977 amended by Executive Order 12148, 20 July 1979.

Executive Order 11990, Protection of Wetlands, 24 May 1977.

Executive Memorandum

Analysis of Impacts on Prime or Unique Agricultural Lands in Implementing NEPA, 11 August 1980.

PUBLIC MEETING ANNOUNCEMENT

SAGAMORE MARSH RESTORATION FEASIBILITY STUDY

TUESDAY, MAY 7, 1996 6:30 p.m.

HOXIE ELEMENTARY SCHOOL, BOURNE, MA *

At the request of the Commonwealth of Massachusetts Executive Office of Environmental Affairs (EOEA), the Army Corps of Engineers New England Division has prepared a Draft Project Modification Report/Environmental Assessment (DPMR/EA) for restoration of saltmarsh at the Sagamore Marsh in Bourne and Sandwich. EOEA has incorporated the DPMR/EA into a Draft Environmental Impact Report (DEIR) evaluating the environmental impacts of the proposed project under the Massachusetts Environmental Policy Act. The Corps and EOEA are circulating the DPMR/EA and DEIR jointly and concurrently for public review. The comment period ends May 24, 1996.

The flow of salt water into Sagamore Marsh has been restricted, causing degradation of the marsh. Large portions of the marsh have become dominated by common reed, an invasive plant species which has compromised the wildlife and fisheries habitat value of the marsh. The Corps investigation examined the feasibility of restoring saltmarsh to portions of Sagamore Marsh without causing flooding of adjacent houses or yards, without affecting the performance of adjacent septic systems, without impacting the salinity of nearby water supply wells, and without impacting navigation in the Cape Cod Canal.

The Corps and the EOEA Wetlands Restoration and Banking Program are holding this joint public information meeting to present the results of the study and to answer questions regarding the proposed project. Technical experts from various fields will be available to assist the public with questions regarding the study.

Copies of the DPMR/EA and DEIR will be distributed in three volumes to the Bourne and Sandwich Town Clerks, Conservation Commissions, Boards of Health, and Public Libraries for public review, and additional copies may be obtained from:

Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02254
Attn: Matthew Walsh
617-647-8647

Executive Office of Environmental Affairs
Wetlands Restoration & Banking Program
100 Cambridge Street
Boston, MA 02202
Attn: Christy Foote-Smith
617-727-9800 x213

* Directions: Take Scusset Beach Road from the Sagamore Rotary. Take a right at the second intersection onto Williston Road. The Hoxie School is on the left.

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, Boston, 02202

WILLIAM F. WELD
GOVERNOR
ARGEO PAUL CELLUCCI
LIEUTENANT GOVERNOR
TRUDY COXE
SECRETARY

Tel: (617) 727-9800
Fax: (617) 727-2754

April 16, 1996

Joseph Ignazio, Director of Planning
Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02154-9149

RE: EOEA Comments on Draft Section 1135 Project Modification Report and Environmental Assessment: Sagamore Marsh Restoration, Bourne and Sandwich, Massachusetts

Dear Mr. Ignazio:

Please accept the following comments which have been compiled by the Wetlands Restoration & Banking Program (WRBP) on behalf of the agencies of the Massachusetts Executive Office of Environmental Affairs (EOEA). These comments are incorporated into the EOEA Draft Environmental Impact Report required for this project under the Massachusetts Environmental Policy Act.

GENERAL COMMENTS

Overall, we find the Corps' Project Modification Report and Environmental Analysis to be readable and relatively thorough. The text describes the complex analysis of project options in a manner readily understood by the lay reader. The technical appendices provide useful back up to the analysis.

While the Corps' analysis is substantially complete, EOEA has some remaining questions that must be addressed before it can embrace any alternative for this project. These questions are based on our need to identify the project design that provides the greatest project benefit (salt marsh restoration) at the lowest cost without increasing the flood risk to adjacent properties or causing other adverse impacts (e.g., to rare species).

MAJOR COMMENTS

Alternatives

The Corps' preferred alternative proposes to restore only 50 acres of the 360 acres of impacted salt marsh. Since the project has at least a 50-year design life, it is important to determine whether there is a project design that could support additional salt marsh restoration efforts at Sagamore Marsh, beyond that proposed by the Corps, without flooding adjacent properties. The true ecologic value of the proposed project for salt marsh restoration must be based on the capability of the project to support both present and future marsh restoration. It is important to weigh the cost of project options against both present and future environmental benefits. Potential future restoration efforts may include removal of dredge spoil, breaching channel dikes, and open marsh water management. Based on a preliminary assessment of the project area performed by Ralph Tiner of WRBP with the Cape Cod Mosquito Control Project, it may be possible to restore up to 20 additional acres of salt marsh simply by breaching the dikes along the channel in the marsh, cleaning or reconfiguring ditches, and creating pools and pannes through open marsh water management techniques. The limiting factor in maintaining and restoring salt marsh at this site is the volume of tidal flow that enters and floods the marsh. Undersizing the culverts could preclude future implementation of these additional restoration opportunities.

It is from this perspective that EOEA poses the following specific questions regarding alternatives.

1. For the preferred alternative, can additional analysis be performed to show whether the 6'x 12' culvert can deliver enough water to the marsh surface to support up to 20 acres of additional salt marsh?

2. The 10'x 20' culvert option provides an additional 21 acres of salt marsh restoration over the preferred alternative (6' x 12'). The 10' x 20' culvert option has the potential to deliver a higher volume of salt water to the marsh, but the cost is much higher than the 6'x 12' culvert alternative, in part due to the proposed automatic tidegates. How much savings could be realized on the cost of the 10'x 20' culvert option if electric sluicegates were installed instead of an automatic tidegates? I understand the Corps has rejected the use of sluicegates with a culvert of this size because of the added flood risk. Could stop logs be put in place to make the flood risk comparable to the 6'x 12' design? Stop logs could be removed as more of the marsh is flooded. The report does not appear to indicate how many sluicegates would be placed in the 6' x 12' opening, nor do we know how many sluicegates might be placed in a 10' x 20' opening. For either option, could one or more sluicegates be left in a closed or partially closed position (except during storm events) to provide the desired flood protection until additional

marsh restoration is completed? Alternatively, could sluicegates be seasonally managed to control flood risks - partially open in summer and fall, partially closed in winter and early spring.

3. Why is it necessary to place tidegates both at the service road and the beach road? The additional cost is significant. We thought that only one set of tidegates would be required and that the other crossing would simply have an open culvert.

4. For the 10' x 20' culvert option, why is it necessary to create the wider channel? Wouldn't spring tides bring in more water when the creek is full and over-topped regardless of the channel width?

5. Could bioengineering be used to stabilize the channel banks and bottom in lieu of using rip-rap?

If an alternative other than the Corps' preferred alternative ultimately is adopted by the Corps and the Commonwealth, other relevant components of the project (e.g., monitoring, operation and maintenance) must be amended accordingly.

Project Design

The DEP Division of Wetlands & Waterways raises the following questions.

1. To reduce construction impacts, could the temporary crossing be eliminated? Instead of constructing a temporary crossing, could traffic be routed from the Canal Service Road to the Scusset Beach Road during the culvert installation under the Service Road? And could traffic be routed to the Canal Service Road while the culvert was being installed under Scusset Beach Road?

2. The EA discusses natural replacement of bottom sediments in the new channel over time. Would it be possible to stockpile a portion of the dredged channel sediments and return them to the new channel bottom to accelerate the replacement process?

Impact to Septic Systems

The Department of Environmental Protection Division of Water Pollution Control (DWPC) provides the following comments with respect to the effect of the proposal on septic systems.

> The report focuses on the restoration project's predicted effect on groundwater levels and the potential impact on septic systems in the area. Essentially, the report states that a

nominal rise in groundwater elevation of 1.2 to 2.4 inches over the existing elevation can be expected from this project. For systems installed with an adequate separation to groundwater (i.e., four feet or greater), this should not create an adverse impact. However, DWPC would strongly suggest that once the project has been completed, groundwater elevations should be monitored in order to field verify the predicted rise and if there is shown to be a significant effect on high groundwater elevation, then steps should be in place to mitigate immediately any adverse impact on leaching facilities affected by a potential groundwater rise.

DWPC is also concerned about systems in the area that may not have adequate separation to groundwater. Any rise in groundwater may further adversely impact those systems' ability to provide adequate treatment of wastewater and efforts should be made to identify those systems at risk and plan to mitigate the impacts associated with them.

Flood Analysis

The following comments are provided by the Department of Environmental Management.

The Corps flood analysis appears to be rather thorough; however, there are a couple of issues which deserve a closer look.

1. Existing flood levels. The Corps analysis shows the 100-year "storm water level" in the marsh to be approximately 4' NGVD (a maximum of 4.2' for a 100-year tide level coincident with a 100-year runoff). The FEMA Flood Insurance Rate Maps (FIRMs) for Bourne and Sandwich show a base (100-year) flood elevation of 10' NGVD. It is impossible to determine the reason for the discrepancy, since it cannot be determined definitively from the FIRMs whether FEMA believed the marsh flooding to be from the culvert to the Canal (the only flooding source the Corps evaluated), overtopping of Phillips Road by Bay flooding, or a combination of both. If the source of flooding is the same for both analyses (i.e., Canal culvert), the discrepancy should be addressed and resolved; if different, the Corps should evaluate the effect of Bay flooding on the project modification.

2. Modified flood levels. Assuming the above issue is resolved, the Corps evaluation of the effects of the project modification appears to be quite thorough and complete. While it is addressed in the Corps report, it is important to recognize the critical nature of proper operation of the sluice gates if the project modification is constructed. While flood elevations would be kept below 4.3 for all events under proper operation, failure to operate the gates during the event consisting of the 100-year storm tide coincident with 100-year runoff would result in a flood level of 5.3, a full foot higher. It is therefore

essential that the gates be operated as proposed at all times.

3. Impact on existing properties. The report identifies only one "developed" property as having a low point in the rear yard as below elevation 4.3, and notes that the low point was beyond the property line. It further notes that "it appears that all land below elevation 6.0 feet NGVD is wetland". However, as noted above, failure to operate the gates could result in flood levels as high as 5.3, and 32 properties have a low point behind the house below elevation 5.3. Failure to operate the gates properly could result in widespread yard flooding.

Rare Species

The following issues are raised by the Natural Heritage and Endangered Species Program (NHESP).

As stated in the NHESP letter to the Army Corps of Engineers dated 27 March 1996 (attached), a population of the state-listed rare Four-toed Salamander (*Hemidactylium scutatum*) inhabits the Sagamore Marsh. At this time there is not enough information available to assess the potential impacts to this population from the proposed Sagamore Marsh Restoration Project. Although we know that this population occurs at an elevation of four to six feet, that information is not sufficiently fine-tuned to allow us to assess whether salt water intrusion will occur in their habitat as a result implementing one of the alternatives for this project. We are not aware that there are any scientific studies that would suggest that this species or their habitat is salt water tolerant, therefore it is important that we proceed cautiously with our assessment of this project. Information given by the Corps in the draft of their Feasibility Report suggests that this area may experience some salt intrusion under the current water regime; however, whether this population is actually subject to occasional salt water intrusion in their habitat is unknown.

In order for NHESP to assess the impacts to this species from the proposed project it is essential that a survey be conducted to measure the elevation of Four-toed Salamander habitat. Brian Butler, the professional herpetologist who discovered this population while conducting a wildlife survey that the Corps contracted for, has the best information about this population and the extent of its habitat, and should be on site while the Corps conducts its topographical survey.

In addition to surveying the elevation at which this population occurs **before** one of the Corps' alternatives for this project is chosen, NHESP strongly recommends that a long-term monitoring program be implemented as a part of this project to ensure the protection of this rare species. Monitoring should included:

1. Vegetation surveys that will quantify the extent (and type) of habitat available to the salamander. Baseline data taken before the new channel is opened will be needed for comparison purposes.

2. Population data collected on an annual basis.

3. Salinity levels monitored multiple times per year.

Each of these monitoring steps will need to be detailed in the near future in consultation with our biologists and other experts.

Along with the monitoring program, a set of safeguards should be in place that would guarantee that if the habitat and the population are being adversely impacted by salt water, the sluice/tide gates will be closed at appropriate high water levels in order to prevent salt water levels from reaching the rare species habitat.

Real Estate Requirements/Temporary Easements

Please add to Section 9.5 of the Feasibility Study the information on landownership of the parcels required for temporary construction easements that appears in Appendix H so that it is clear to the reader that only public properties are involved. The language in Section 9.7 Estimated Cost which states, "There is not expected to be any cost associated with temporary construction easements, since the land is owned by local, State, and Federal Governments..." could be repeated in section 9.5.

Monitoring

Groundwater Monitoring: The Technical Services Group of the Division of Water Supply has the following comments and recommendations regarding the groundwater monitoring plan outlined in Appendix F.

1. The Corps proposes to measure and record the specific conductance of the groundwater at the Beach Well and the ten surrounding observation wells during the plans and specifications phase of the monitoring plan. It is recommended that the Corps also develop baseline chloride data during this period by sampling the groundwater at each well at least once for chlorides.

2. It is recommended that an additional water table well be installed at the location of

BHW490-150 during the construction phase of the restoration project to permit monitoring of ambient water table fluctuations during the proposed five year monitoring period. Water table data collected at this well will aid in the analysis and interpretation of groundwater fluctuations recorded at monitoring wells located on the perimeter of the marsh.

3. The Corps proposes to monitor only specific conductance at the Beach Well and the surrounding observation wells during the monitoring period. While field measurements of specific conductance can be used to estimate relative changes in the concentration of total dissolved solids, these measurements are not directly comparable to the chloride concentration within the wells. Chloride is the primary contaminant of concern at the Beach Well and has a federal secondary drinking water standard of 250 mg/l. It is recommended that the Corps use specific conductance as its sole water quality indicator parameter only until a significant increase is experienced in any of the wells being monitored. If and when such an increase is encountered, the Corps should immediately begin sampling for chlorides at all of the wells.

4. The Corps should develop a contingency plan that outlines what actions are to taken should a significant increase in chloride concentration be identified at either the Beach Well or at any of the surrounding observation wells. It is recommended that a chloride concentration of 125 mg/l (half of the secondary drinking water standard) at the Beach Well or a three hundred percent increase in concentration at any of the observation wells, relative to the established baseline concentrations, trigger implementation of the contingency plan.

Ecologic Monitoring

The Wetlands Restoration & Banking Program and Coastal Zone Management provide the following commentary on the proposed ecologic monitoring.

Overview: The Corps proposes to establish 10 permanent plots for assessing marsh vegetation changes and 3 plots for evaluating eelgrass beds. Marsh data will be collected along two transects -- one near existing Transect 1 and another between Transects 2 and 4. Sampling will be done annually in August for 5 years following project implementation and immediately after implementation. For the marsh plots, the following data will be collected: depth of soil water during low tide, depth of flooding relative to surface elevation at high and low water during spring and neap tides, plant species composition, percent cover, and height and density of common reed. For eelgrass, the percent cover, height, and density of eelgrass plants will be gathered. Continuation of sampling during the 5-year period will depend on sampling results. An aerial survey will be conducted at the end of the 5th growing season (scale 1" = 600'); results will be compared with 1993 aerial photos.

Comments. August sampling is fine, but the initial sampling should be done immediately before project construction. The Feasibility Study (9.6 Monitoring Plan) states that baseline data will be gathered during the development of plans and specifications and during the nine month construction phase. But the Monitoring Plan in Appendix F only mentions beginning sampling after project implementation. Baseline data must be gathered prior to construction.

Percent cover should be estimated for all plant species observed in each sample plot, not only for Phragmites. The height of other species, especially smooth cordgrass, should also be recorded, since it is well established that smooth cordgrass (Spartina alterniflora) has different height forms related to the soil salinity (low marsh, pannes, high marsh) and other species are similarly affected.

Sampling should be conducted throughout the study and not eliminated depending on results. For monitoring purposes, it is important to sample all sites for five years, regardless of intermediate results. There may be further changes in vegetation that are worth noting.

Sampling should include soil salinity. Collect water within the root zone by squeezing water from a soil sample collected 6 to 12 inches from the marsh surface. Collections should avoid periods of extreme weather conditions (e.g., coastal storms or heavy rains). If such events do occur in August, sampling should be done at least one week later.

Regarding the hydrology at the sampling sites, how is depth of flooding at low and high water during spring and neap tides determined? Is it observed or predicted? If the former, there may be significant lag time between observations and it might be possible to evaluate additional vegetation plots.

Sampling size is not specified. We recommend that two 1.4m x 1.4m plots be evaluated at each sampling station in the marsh community. Density can be determined in a subplot -- a 1m x 1m plot within the larger plot. If plots are established in the shrub/forested swamp, they should be larger, with recommended 5m x 5m for shrub swamps and 10m x 10m for forested swamp.

Presently, two transects are scheduled for sampling, one near Transect 1 and another between Transects 2 and 4. A suggested location for the latter transect is shown on the attached map. It attempts to cover areas predicted to revert to salt marsh plus areas where Phragmites is supposed to remain. Eight plots should be established along this transect and four plots along Transect 1 (their locations have been marked on the attachment). These plots should give us a good idea of what the results are going to be within the region where salt marsh restoration is predicted. It also seems necessary to establish two extra plots (one on each end of the two transects) in the adjacent shrub/forested swamp to monitor any impacts on these communities. An additional transect above Transect 4 would provide useful information on whether the effect of increasing salt water into the Sagamore Marsh is occurring further upstream than anticipated (see attachment). Five plots should be located in this area.

The aerial photography survey and photointerpretation analysis at the end of the five year monitoring period is acceptable. However, it is best to compare these results against conditions in 1996 or 1997 whenever the project is initiated. It is, therefore, recommended that a 1996/97 aerial survey be conducted to identify existing conditions. This photography should be interpreted as soon as possible after its acquisition, so that field investigations can verify different height forms of Phragmites and the variety of shrub and forested communities that presently exist.

The proposed eelgrass monitoring efforts appear sufficient to measure the predicted return of this aquatic vegetation after the construction related impacts to the reconfigured channel, although additional information on the size of plots and location would be helpful. It is requested that the when the Corps are sampling the eelgrass population, core samples for benthic invertebrates also be taken, as was completed for the EA. The rationale is that it is highly possible that the eelgrass population will not return nor recover to its pre-construction conditions in the channel, and therefore measuring additional channel biota will document the recovery of other species to this habitat.

Additional monitoring could be performed to further evaluate changes in hydrology, seasonal variations in salinity, annual marsh accretion rates, and fish and wildlife utilization. The Wetlands Restoration & Banking Program will seek funding and/or volunteer assistance to perform monitoring beyond that proposed by the Corps.

It has been suggested further that the Sagamore Marsh restoration project will provide an unparalleled opportunity to research methods and effects of salt marsh restoration. WRBP will seek academic and other research cooperators to pursue this.

WRBP requests that the Corps provide monitoring data in a format which fits the wetlands restoration data base currently under development by WRBP.

Mosquito Control Monitoring

Please refer to the attached letter from John W. Doane, Assistant Superintendent, Cape Cod Mosquito Control Project, dated April 2, 1996, which states, in part,

> "As to a monitoring plan for the adult population of mosquitoes, we will conduct surveillance throughout the restoration process. Mosquitoes will be collected and identified. I have enclosed a list of mosquitoes that have been trapped in the Sagamore Marsh area in recent years. When the area becomes more of a salt marsh the potential for salt water mosquitoes increases. The ability to control the salt water mosquito is a much easier process with the coming and going of the tide each day. We just need to make sure that the water does not stand because standing water is where the mosquito larvae hatch."

Rare Species Monitoring

Please refer to the section above regarding rare species for specific requirements.

Operation and Maintenance

The Department of Environmental Management (DEM) has prepared the following Management Plan for the Sagamore Marsh Restoration Project.

> The Management Plan for the operation and maintenance of the Project Modification will be performed by DEM in accordance with Article VIII of the "Project Cooperation Agreement Between the Department of the Army and the Executive Office of Environmental Affairs for Modification of the Cape Cod Canal" which must be signed prior to commencement of the project. Article VIII states that "...the Non-Federal Sponsor shall operate, maintain, repair, replace, and rehabilitate the entire Project Modification or the functional portion of the Project Modification, at no cost to the (federal) Government..."
>
> Under the Corps' preferred alternative, maintenance will be addressed by DEM as described in Section 9.3.2 of the "Draft Section 1135 Feasibility Report and Environmental Assessment" for the restoration of Sagamore Marsh, U.S. Army Corps of Engineers, 1996 which states that "...the sluice gates, stop log frames, and culverts will be inspected approximately quarterly. During quarterly inspections, the sluice gates will be inspected to ensure that all parts are freely moving and that the gates continue to open and close, the stop log frames will be inspected for integrity, and any large debris will be cleared from the culverts and gate areas."

Since the Army Corps has equipment and personnel at the Cape Cod Canal monitoring flood levels on a twenty-four hour basis, it is anticipated that operation of the tidegate, as described in Section 9.3.1, will be carried out by the Army Corps of Engineers under a future, separate Memorandum of Understanding.

The Corps has estimated that the annual cost to the Commonwealth for operation, maintenance, repair, replacement and rehabilitation will be $5,000. The Commonwealth is willing to assume responsibility for labor costs associated with the regular inspection and maintenance of the project. In order for the Commonwealth to approve the project, however, agreement must be reached on a limit to the Commonwealth's financial obligation for repair, replacement, and rehabilitation.

Remediation

What are the performance criteria for evaluating wetland restoration success for this project? What remedial measures will the Corps take if the project does not perform as projected?

OTHER COMMENTS

Feasibility Study

2.1 Coastal America Please mention here that the Coastal America Partners (Including the Department of the Army), and the Massachusetts Executive Offices of Transportation & Construction and Environmental Affairs, have signed a "Resolution to Restore Massachusetts Wetlands". This project represents a first major effort to implement the Resolution.

2.3 Agency Please note that the Wetlands Restoration & Banking Program was the lead agency for the Commonwealth and add the DEP Division of Wetlands & Waterways to the list.

Figure 2. The figure does not show the location of the access road from the temporary crossing to the Canal Service Road on the east side of the channel.

3.1 Existing Conditions In the second paragraph, third sentence, it should be noted that productivity in this context refers to detrital export only, not to wildlife productivity.

Environmental Assessment

Figure 5 Figure 5 shows the location of core samples for evaluating benthos. Why was sampling restricted to this area and not undertaken further upstream in the major portion of the Phragmites marsh? It is impossible to predict changes in macroinvertebrates as well as fish fauna without knowing what species exist in this portion of Sagamore Marsh.

Fish and Wildlife Evaluation The EA is based heavily on the literature with very little direct observations of fish and wildlife species. Is this typical for an EA? Baseline fish and wildlife studies will be necessary to monitor post restoration changes.

EA-15 Add the following to the first paragraph when presenting the merits of the project: "access to Sagamore Marsh by estuarine organisms will be greatly increased, thereby strengthening the ecologic link between the Marsh and Cape Cod Bay."

EA-17 What is the current salinity of the tidal creek water in Sagamore Marsh at different locations? Is there any information on seasonal changes, especially spring v. summer v. fall?

EA-17 Change in Wetland Area This section states that the project would have a "minimal" effect on location of current wetlands. The Project Modification Report concludes in Section 9.5 that, "No lands which are currently non-wetland are expected to be changed to wetland by this project". These sections appear to be inconsistent on a rather crucial matter.

Table 8 (After EA-20)
1. Why - for swallows and chimney swifts? They feed over salt marshes.
2. Why + for kingfisher? They're more typical of freshwater swamps and marshes.
3. The extensive list of mammals, in the absence of any actual surveys, raises many questions. How will skunk benefit from salt marsh? Wouldn't deer use drop with an increase in salt marsh? The white-footed mouse is referenced in the text, but not in this table.
4. Is it really likely that the project will have no significant impact on most of the herps listed? It may be that where the salt marsh restoration occurs there is already brackish marsh and no habitat for these species; but this should be made clearer. If this is true, why even list these species since they are not in the affected area?

EA-22 Mosquitoes The EA states that, "The state of Massachusetts will institute Open Marsh Water Management (OMWM) to control mosquitoes once the tidal flow is restored." The Commonwealth, through the Cape Cod Mosquito Control Project, and in cooperation with the EOEA Wetlands Restoration & Banking Program will explore the potential OMWM and may implement OMWM or other mosquito control measures as indicated.

EA-23 Use of bioengineering techniques would improve water quality more than rip-rap. This could be included on EA-27 as an action to minimize adverse impacts to the environment.

The EOEA Wetlands Restoration & Banking Program believes that the Sagamore Marsh Restoration project can provide significant benefits to the Commonwealth by restoring one of our most valuable and threatened resources - salt marshes. We look forward to continuing to work with the Corps to develop and implement this important Coastal America initiative.

Sincerely,

Christy Foote-Smith

Christy Foote-Smith, Director
Wetlands Restoration & Banking Program

The Commonwealth of Massachusetts
State Reclamation Board

CAPE COD MOSQUITO CONTROL PROJECT

86 WILLOW STREET
YARMOUTH PORT
MASSACHUSETTS 02675

TELEPHONE: (508) 775-1510
(508) 362-9757

OSCAR W. DOANE, JR.
SUPERINTENDENT

JOHN W. DOANE
ASSISTANT SUPERINTENDENT

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WAYNE MELVILLE
HARWICH

April 2, 1996

Executive Office of Environmental Affairs
Ms. Christy Foote-Smith, Director
Wetlands Restoration & Banking Program
100 Cambridge Street - 20th Floor
Boston, MA 02202

RE: SAGAMORE MARSH

Dear Christy:

I am writing in response to your questions, conveyed to me by Mr. Ralph Tinner at our April 1st meeting.

Our role in maintaining ditches in the Sagamore Marsh for mosquito control purposes will be done on a routine basis at the completion of restoration. Within the first five years of allowing salt water back into this marsh, as proposed by the Army Corps of Engineer, our mosquito control efforts and cleaning of ditches would not be one I would classify as routine. In the early stages of trying to reclaim this marsh, we will spend a lot of time surveying the area to determine what areas are going to be a mosquito breeding problem. When these areas of concern are located we will work to manage them. This management is best completed by allowing the salt water into these areas thus giving the natural predators access to eat the mosquito larvae. Further, the salt marsh would be enhanced by the flow of water.

As to how much work we would have to do in the first few years, it would depend on how quickly the area reverts to salt marsh. Therefore, it would be hard to place an exact dollar figure as to what it would cost for the surveillance and maintenance of the ditch system. I do not think it would cost more then $20,000.00 annually in any of the first five years. Year one would probably be just surveillance, where years two and three would involve cleaning the ditches and would cost more then the first year. I do believe a $20,000.00 figure would be more then enough in any one year.

In regards to the test plots that you would like created to see if there are seeds within the top soil that may germinate, we are willing to help in that effort by clearing a few areas. My understanding is that they would be 30' x 30' square. I do question the reasoning behind these tests because whatever seeds may germinate would be doing so in a fresh water environment. The inundation of the area with salt water will certainly impact the species composition.

As to a monitoring plan for the adult population of mosquitoes, we will conduct surveillance throughout the restoration process. Mosquitoes will be collected and identified. I have enclosed a list of mosquitoes that have been trapped in the Sagamore Marsh area in recent years. When the area becomes more of a salt marsh the potential for salt water mosquitoes increases. The ability to control the salt water mosquito is a much easier process with the coming and going of the tide each day. We just need to make sure that the water does not stand because standing water is where the mosquito larvae hatch.

In response to your question concerning possible increases in the greenhead fly population, I believe that the presence of greenhead flies, *Tabanus nigrovittatus* complex, would be a good sign that this project has worked. That is you have a viable salt marsh. If they were to become a nuisance in the area we would simply expand our trapping program to include this area.

Sincerely,

John W. Doane

John W. Doane
Assistant Superintendent

JWD/mal
Enc.

Mosquito Species Trapped at Sagamore Marsh*

Species	Larval Habitat	Abundance
Aedes cantator	Brackish water	High - This is the most abundant species at this site.
Aedes canadensis	Fresh water - semipermanent pools	Low
Aedes cinerus	Fresh water - grassy pools	Low
Culex pipiens	Fresh water - artificial containers (e.g. catch basins)	Low
Coquillettidia pertubans	Fresh water - This species lives an the roots of vegetation (e.g. cattails)	Low

* Adult mosquitoes were trapped using Bioquip light traps.

27 March 1996

Joseph Ignazio
New England Division, Army Corps of Engineers
424 Trapelo Rd.
Waltham, MA 02254-9149

Re: Sagamore Marsh Restoration
Bourne & Sandwich, MA
NHESP File No: 96-333

Dear Mr. Ignazio,

Thank you for contacting the Natural Heritage and Endangered Species Program for information regarding state-listed rare species in the vicinity of the above referenced project. I have reviewed the project and would like to offer the following comments.

As you are aware, a population of the state-listed rare Four-toed Salamander (*Hemidactylium scutatum*) has been found in the Sagamore Marsh. This species is protected under both the Massachusetts Endangered Species Act (M.G.L. c.131A) and its implementing regulations (321 CMR 10.00), and the state's Wetlands Protection Act (M.G.L. c.131, s.40) and its implementing regulations (310 CMR 10.00). The information that you provided to us in your letter dated Jan. 11, 1996, indicates that the proposed maximum salt water levels in the marsh would be less than 4 feet NGVD. Using the topographical maps that you provided along with your letter and the information on the location of this population that was provided by Brian Butler, it appears that this population occurs between the 4 feet and 6 feet elevation marks. In a telephone conversation that I had today with Ralph Tiner at the Wetlands Restoration and Banking Program, he informed me that one scenario for restoration would call for salt water levels to reach 5 feet.

Given that our estimation of the elevation of the salamander habitat is extrapolated from two different sources, your elevation map and Brian Butlers location marked on a U.S.G.S. topographical map, it appears that it will be necessary to gather more information on the precise elevation of the Four-toed Salamander's habitat in this area. I would recommend that the Corps survey the elevation of the salamander's habitat with Brian Butler along to delineate the extent of the habitat boundaries. We are not aware of any information that would suggest that these salamanders are salt tolerant or that the sphagnum moss that provides habitat for them is salt tolerant, therefore, we need to safeguard against salt intrusion into their habitat. I have enclosed a fact sheet on this species for your information.

Please do not hesitate to call me at (508) 792-7270 x.161 if you have any questions.

Sincerely,

Hanni Dinkeloo
Environmental Reviewer

cc. Christy Foote-Smith, EOEA, Wetlands Restoration and Banking Program

to file
10174

Commonwealth of Massachusetts
Executive Office of Environmental Affairs

Department of Environmental Protection

William F. Weld
Governor
Argeo Paul Cellucci
Lt. Governor

Trudy Coxe
Secretary
David B. Struhs
Commissioner

MEMORANDUM

TO: Christy Foote-Smith/Director/WR&BP/EOEA/Boston

CC: Larry Dayian/Section Chief/DWS/DEP/SERO

RECEIVED
DEC 26 1995
MEPA

THRU: Paul Blain/Senior Hydrogeologist/DWS/DEP/Boston PGB

FROM: Criss Stephens/Hydrogeologist/DWS/DEP/Boston TCS

DATE: 12 DEC 95

SUBJECT: Sagamore Marsh Restoration Project

The Technical Services Group of the Division of Water Supply has completed its review of the draft report entitled Hydrogeology and Analysis of the Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts. This report is dated November 1, 1995 and was prepared by the U.S. Geological Survey as part of a cooperative investigation with the U.S. Army Corps of Engineers. The purpose of this investigation was to develop a description of the existing hydrogeology and groundwater flow system of the Sagamore Marsh area and to evaluate the potential impacts of the proposed salt marsh restoration to the North Sagamore Water District's Beach Well and the septic systems located along the barrier beach.

The draft report discusses 1) the stratigraphy of the Sagamore Marsh area; 2) the patterns of groundwater flow and the effects of tidal fluctuations; 3) the zone of contribution for the North Sagamore Water District's Beach Well; and, 4) the response of the flow system to increased tidal stages within the marsh.

Boring samples and geophysical logs were used to determine the hydrogeologic stratigraphy of the area. Geologic deposits were determined to consist of glaciolacustrine and deltaic sediments that extend to a depth of greater than 175 feet. These sediments are overlain within the marsh by deposits of fibrous peat, clayey peat and marine clay. Along the coast, younger marine sediments overlie the glacial deposits. The deltaic deposits consist of fine-to-coarse sands and constitute an important aquifer in the area that is, for the most part, unconfined.The low vertical and horizontal hydraulic conductivities of the fine-grained marsh sediments cause confining conditions to occur locally beneath the marsh.

The U.S.G.S.'s analysis of the data generated during the investigation indicates that the zone of contribution for the Beach Well extends northwestward from the well toward Great Herring Pond. The Survey's numerical modelling of groundwater flow suggests that the projected increases in tidal stage associated with the proposed marsh restoration should have a negligible effect on the well's zone of contribution.

Analysis of the hydraulic conductivity and diffusivity of the marsh sediments demonstrates that tidal pulses are rapidly attenuated in the unconfined aquifer and that increases in tidal stage will have little effect on water table elevations along the barrier beach and the septic systems located there. Furthermore, tidal fluctuations in Cape Cod Bay were shown to exert a greater influence on groundwater levels along the barrier beach than fluctuations within the marsh.

Based upon our review of the data submitted, we concur with the U.S.G.S.'s conclusion that the Sagamore Marsh Restoration Project proposed by the U.S. Army Corps of Engineers should not pose a significant threat to either the North Sagamore Water District's Beach Well or to the septic systems of the homes located on the barrier beach.

We recommend that a groundwater monitoring program be designed and implemented that would address the following:

1. the changes in groundwater quality in and around the Beach Well,
2. the changes in water table elevations along the barrier beach, and
3. the ambient groundwater quality and groundwater elevations of the Sagamore Marsh area.

This monitoring program should be implemented as soon as possible, prior to design and construction, and continue until steady state groundwater conditions have been re-established within the study area.

Questions or comments regarding the above memorandum should be directed to me via e-mail or by phone at 617/292-5657.

DS

Commonwealth of Massachusetts
Executive Office of Environmental Affairs

Department of Environmental Protection

D E P

William F. Weld
Governor
Trudy Coxe
Secretary, EOEA
Thomas B. Powers
Acting Commissioner

RECEIVED
MAY 2 8 1996
MEPA

January 4, 1995

Christy Foote-Smith, Director
Wetlands Restoration & Banking Program
Executive Office of Environmental Affairs
100 Cambridge Street
Boston, MA 02202

Dear Christy:

In response to your letter of December 27, 1994 regarding the Sagamore Marsh wetlands restoration project, I believe that this project is eligible to be permitted under 310 CMR 10.53(4), which gives the issuing authority discretion to permit freshwater wetlands to be altered as necessary for wetlands improvement projects. Specifically, that provision grants limited project status for projects altering inland resource areas "which will improve the natural capacity of a resource area(s) to protect the interests identified in M.G.L. c. 131, s. 40." However, no such project may be permitted without a variance if it will have an adverse effect on rare wildlife habitat.

310 CMR 10.53(4) does not directly address the question of whether a project which would change one type of resource area into another type of resource area (much less an inland resource area into a coastal resource area) could be considered an improvement project. However, neither are such projects explicitly barred from consideration. The burden would be on an applicant to demonstrate that a proposed project will, overall, "improve the natural capacity of the resource area(s) to protect the interests identified" in the Wetlands Protection Act. To the extent that the resource areas to be altered in the Sagamore Marsh restoration project consist of phragmites monoculture, I would think that such a demonstration could reasonably be made if it can also be shown that there will be no significant adverse effect on protected statutory interests such as flood control and protection of water supply. While not determinative, it is important to note that this project is proposed by state and federal agencies, the primary purpose of which is to protect, create and restore wetlands.

Regarding the salt marsh regulations at 310 CMR 10.32(5), it is not clear to me whether these are pertinent to the Sagamore Marsh project since I have not yet seen the complete project proposal. That provision states that proposed projects in a salt marsh, on lands within 100 feet of a salt marsh, or in a body of water adjacent to a salt marsh which destroy any portion of the salt marsh or have an adverse effect on the productivity on the salt marsh may only be permitted if the project is one which will restore, rehabilitate or create a salt marsh. Thus, for example, if a small portion of an existing salt marsh were to be impacted by the construction of the hydrological connection to reintroduce tidal flushing to Sagamore Marsh, the project would still be eligible for permitting by the issuing authority notwithstanding the otherwise strict performance standard for projects impacting salt marsh.

I hope I have provided answers to you questions. Please feel free to contact me or Steve Pearlman if you would like to discuss this further.

Sincerely yours,

Carl

Carl F. Dierker
Acting Director
Division of Wetlands & Waterways

cc: Dan Gilmore, DWW/SERO
Bob Gray, Bourne Conservation Commission

cfssagq.ues

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02254-9149

REPLY TO ATTENTION OF

October 7, 1994

Planning Directorate
Basin Management Division

To All Interested Parties:

This letter is to clarify the date of the Public Meeting on the Sagamore Marsh Restoration Feasibility Study. The letter which I recently sent to you dated September 20, 1994 incorrectly stated the date of the Public Meeting. The meeting will be held on Monday, October 24, 1994 from 7:00-9:00 p.m. at the Hoxie Elementary School* in Bourne, Massachusetts. I apologize for any inconvenience.

The feasibility study is being conducted by the Army Corps of Engineers, New England Division in Waltham, Massachusetts at the request of the Commonwealth of Massachusetts Executive Office of Environmental Affairs.

If you have any questions, please contact the Study Manager, Matthew Walsh, at (617) 647-8647 or Mike Keegan at (617) 647-8087.

Sincerely,

Joseph L. Ignazio
Director of Planning

* Directions: Take Scusset Beach Road from the Sagamore Rotary, then take a right at the second intersection onto Williston Road. The Hoxie School is on the left.

W/ Walsh

September 20, 1994

Planning Directorate
Basin Management Division

To All Interested Parties:

At the request of the Commonwealth of Massachusetts Executive Office of Environmental Affairs, the Army Corps of Engineers New England Division in Waltham, Massachusetts is conducting an environmental restoration feasibility study at Sagamore Marsh in Bourne and Sandwich, Massachusetts.

This letter is to inform all interested parties that the Corps of Engineers and the Commonwealth will be holding a Public Meeting regarding the study on Thursday, October 27, 1994 at the Hoxie Elementary School in Bourne, Massachusetts. A Public Meeting Announcement is enclosed.

This letter is also to inform you that, in conjunction with the study, the firm of Guerriere and Halnon Inc. will be performing a topographic survey of the Sagamore Marsh and adjacent areas under contract to this office. The survey is expected to take four to six weeks and is expected to commence in approximately one week.

Guerriere and Halnon Inc. will be performing work at the following locations: in the marsh; in the vicinity of the outlet at the Cape Cod Canal; and along Phillips Road, Williston Road, Marsh Pond Road, Vineyard Circle, Sachem Drive, and Pilgrim Road. They will also be determining the elevations of houses and yards adjacent to the marsh. This will include elevations outside of all houses on the west side of Phillips Road, and outside of some houses located at lower elevations on Marsh Pond Road, Vineyard Circle, and Sachem Drive. Photos of the front of the houses and the rear yards will be taken so that the location of the elevations can be identified in the office by employees of the Corps working on the study.

If you have any questions, please contact the Study Manager, Matthew Walsh, at (617) 647-8647 or Mike Keegan at (617) 647-8087.

Sincerely,

Joseph L. Ignazio
Director of Planning

Enclosure

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02254-9149

REPLY TO
ATTENTION OF

September 21, 1994

Planning Directorate
Basin Management Division

PUBLIC MEETING ANNOUNCEMENT

SAGAMORE MARSH RESTORATION FEASIBILITY STUDY

MONDAY, OCTOBER 24, 1994 7:00 - 9:00 p.m.
HOXIE ELEMENTARY SCHOOL, BOURNE, MA *

At the request of the Commonwealth of Massachusetts Executive Office of Environmental Affairs, the Army Corps of Engineers New England Division is conducting an environmental restoration feasibility study at Sagamore Marsh in Bourne and Sandwich. The study will investigate the feasibility of restoring the former habitat value of the marsh.

The flow of salt water into Sagamore Marsh has been restricted, causing an alteration of the vegetation and reducing the habitat value of the marsh for fish and wildlife. There is an opportunity to restore the habitat value at this 250-acre site. The study will investigate the feasibility of restoring the marsh without increasing the flooding potential of homes, yards, and septic systems; without causing intrusion of salt water into the water supply; and without causing adverse impacts to navigation in the Cape Cod Canal.

This is the second Public Meeting to be held on this study (the first was held on May 11, 1994 in Sandwich). The purpose of this meeting is to update all interested parties on the status of the study, to present the study schedule, to discuss the benefits of marsh restoration, and to hear the views of all interested parties.

If there are any questions, please contact the Corps of Engineers' Study Manager, Matthew Walsh, at (617) 647-8647.

* Directions: Take Scusset Beach Road from the Sagamore Rotary, take a right at the second intersection onto Williston Road. The Hoxie School is on the left.

COASTAL ZONE MANAGEMENT

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street
Boston, Massachusetts 02202

TO: Bob Gray, Mark Galkowski
FROM: Pam Rubinoff
RE: Sagamore Marsh Restoration
DATE: April 7, 1994

****

The Corps of Engineers (COE) has recently submitted its preliminary assessment for restoration of Sagamore Marsh. They are looking at installing large culverts at the location of the existing 4' culvert from the canal to the marsh to improve tidal flushing throughout the marsh system.

At this time the COE is awaiting approval and funding for the study and design of the project. It is anticipated that this will be approved rather quickly and that their study can begin this spring. The larger picture is just as exciting. The state and the Federal agencies are developing a wetlands restoration partnership, with the goal of cooperatively planning and implementing wetlands restoration projects. It is anticipated that a June 1 event at Scusset Beach will highlight both the state/federal resolution and the initiation of the Sagamore Marsh restoration project.

We would like to "initiate" the Sagamore Marsh project with a local workshop in mid May. The goals are 1) to discuss the project, its benefits, and its timeline; 2) to begin to get feedback from the abutters, public, and local officials; and 3) to set the stage for the bigger wetlands restoration initiatives throughout Cape Cod and the Commonwealth. The participants would include the local officials and boards, abutters, interested public, as well as regional, state, and federal agency representatives.

I would like to discuss this with you so that we can have a successful workshop and project initiation. I wonder if you can assist me by providing the following:

- List of local officials, interested public
- List of abutters and addresses
- Confirmation of a date and time (proposed May 10 or 11)
- Initial hurdles that we should begin to address

I will give you a call early next week. Thanks. I am really looking forward to working on this project with the two towns.

cc:
Christy Foote-Smith, WRBP
Jack Clarke, CZM
Cape Cod Commission
Mike Kegan, COE

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, Boston, 02202

WILLIAM F. WELD
GOVERNOR
ARGEO PAUL CELLUCCI
LIEUTENANT GOVERNOR
TRUDY COXE
SECRETARY

Tel. (617) 727-9800
Fax: (617) 727-2754

February 11, 1994

Colonel Brink Miller
Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

Dear Colonel Miller:

Thank you for your letter of November 23, 1993, explaining the status of the Coastal America studies for restoring Sagamore Marsh. As you stated in your letter, there is a potential to restore up to 250 acres of degraded salt marsh. The estimated cost of the project is $2,560,000 with a 25% non-federal cost share required. You have requested that a letter of support for the proposed modification be submitted to your office. This letter should acknowledge the state's understanding of its obligation and indicate an intent to pursue budgetary actions necessary to make state funds available prior to your office advertising a construction contract (projected for October 1995).

The Commonwealth has adopted a policy of no net loss of wetlands in the short term and a net gain in the long term. In keeping with, and to further implement this policy, a new Wetlands Restoration and Banking Program has been established within EOEA. Massachusetts has, therefore, made a major commitment to restoring degraded and lost wetlands across the state. This project represents a significant opportunity for wetlands restoration and, therefore, exemplifies what this new program is all about.

The Sagamore Marsh project represents a major investment of resources for both the Commonwealth and the Corps of Engineers. Based on available information, the Commonwealth believes this project is of major significance to our wetlands restoration efforts and our coastal initiatives overall, and has a high likelihood of success. We are prepared to move forward aggressively to secure the state's share of funding for this project. Therefore, I encourage the Corps to proceed with the next stage of project development - the preparation of the Feasibility Report and Environmental Assessment. From conversations with your staff, I understand that the Environmental Assessment will include appropriate submissions to our MEPA office. This public review and disclosure process will be invaluable in refining the design of the project to ensure that environmental goals will be met.

If you have any questions, please contact Pam Rubinoff of the Coastal Zone Management Office at (508)362-3828 or Christy Foote-Smith of the Wetlands Restoration and Banking Program at (617)292-5692.

Sincerely,

Trudy Coxe
Secretary

TC:CRS:PBR:cpt

cc:
Dick Heidebrecht, COE Planning Directorate
Bill Hubbard, COE Planning Directorate
Leo Roy, EOEA
Christy Foote-Smith, DEP\WRBP
Pam Rubinoff, MCZM
Alan Steinert, EOEA
Janice Tatarka, EOEA
Carl Dierker, DEP
Richard Carafoli, Scusset State Beach - DEM Parks
Mark Forest, Congressman Studds Office
Representative Tom Cahir
State Senator Therese Murray
Bourne Conservation Commission
Sandwich Conservation Commission
John Doane, Barnstable County Commissioner
Armando Carbonell, Cape Cod Commission

3 DEC 1993

Planning Directorate
Basin Management Division

Ms. Trudy Coxe, Secretary
The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street
Boston, Massachusetts 02202

Dear Ms. Coxe:

The purpose of this letter is to inform you of the status of initial studies concerning the feasibility of restoring Sagamore Marsh, which is located adjacent to the east end of our Cape Cod Canal project. The overall study is being conducted under authority contained in Section 1135 of the 1986 Water Resources Development Act, as amended.

The initial appraisal recommends restoration of up to 250 acres of former salt marsh from its present degraded condition which consists primarily of fresh water wetland overgrown with common reed (Phragmites australis) and shrubs. This would be accomplished by enlarging an existing 42 inch RCP culvert and channel system that connects the marsh to the canal. The new culvert and channel will be sized to restore tidal flushing and salinity levels in the marsh. This would restore the estuarine habitat, discourage the growth of common reed and allow the recolonization of the marsh by salt marsh cordgrass (Spartina alternaflora), salt meadow grass (Spartina patens) and other salt marsh grasses. A small portion of the marsh near the end of the existing channel presently receives sufficient tidal flushing to allow growth of salt marsh vegetation, but a much larger opening is needed to provide adequate tidal fluctuation in the remainder of the marsh. Enlargement of channels within the marsh may also be required to distribute tidal water to locations within the restoration area.

A preliminary evaluation of potential modifications to the existing culvert and channel determined that reestablishing tidal fluctuations in the marsh would cost an estimated $2,560,000. This would include $210,000 for preparation of the Feasibility Report and Environmental Assessment, about $200,000 for Plans and Specifications and approximately $2,150,000 for construction. Under Section 1135, total project costs are shared 75 percent Federal and 25 percent non-Federal. Feasibility study and Plans and Specifications costs are initially funded by the Federal government, and are included as part of the total project modification costs. Based on this formula and current estimates, the total non-Federal share for design and construction would be $640,000. In addition, the non-Federal sponsor would be responsible for 100 percent of the future incremental maintenance costs of the project. Estimated operation, maintenance, repair, rehabilitation and replacement costs for the project are $1,500 per year for the 50 year economic life of the project.

Prior to completion of the initial appraisal and submission to the Office, Chief of Engineers for approval and provision of feasibility study funds, we request a letter from the State supporting the proposed modification. This letter should indicate that the State understands its obligation and intends to pursue budgetary actions so that funds will be available prior to this office advertising for a construction contract. It is estimated that Plans and Specifications will be completed and the contract advertisement and award process will begin in October 1995. As the non-Federal sponsor, the State will also be required to sign a Project Cooperation Agreement indicating that it will:

a. Provide all lands, easements, rights-of-way, including suitable borrow and dredged material disposal areas, required for the project modification which are not otherwise available due to the construction of the existing project. Accomplish or arrange for accomplishment, all relocations necessary for implementation of the project modification. If the value of such lands, easements, rights-of-way, relocations and disposal areas (LERRD) represents less than 25 percent of the total project modification costs, provide a cash contribution in the amount necessary to make the total contribution equal to 25 percent.

b. Assume responsibility for 100 percent of the incremental operation, maintenance, repair, rehabilitation and replacement (OMRRR) costs associated with the project modification.

c. Hold and save the United States free from damages due to construction, operation and maintenance of the project, except where such damages are due to the fault or negligence of the United States or its contractors.

Based on preliminary studies, non-Federal project implementation costs are estimated at $640,000. Since the land where modifications are required is presently owned by the Corps, LERRD should not be required. However, this will be fully evaluated during the feasibility phase. Annual OMRRR is currently estimated at $1,500. This would include monthly operation and maintenance of any required tide gates and coordination with Corps staff regarding potential coastal flooding events.

Upon receipt of a letter of support from the State, our appraisal will be forwarded to Washington for approval of funding of the feasibility study. If you have any questions regarding this letter or upcoming study, please contact me at (617) 647-8220, or the Study Manager, Richard W. Heidebrecht, at (617) 647-8513.

I have taken the liberty of forwarding a copy of this letter to your point of contact, Ms. Pam Rubinoff, MCZM Regional Coordinator.

Sincerely,

Brink P. Miller
Colonel, Corps of Engineers
Division Engineer

Copy Furnished:

Ms. Pam Rubinoff
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